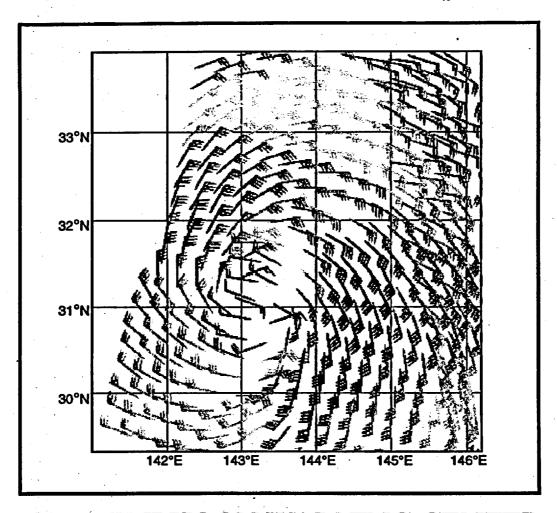
1996 ANNUAL TROPICAL CYCLONE REPORT



JOINT TYPHOON WARNING CENTER GUAM, MARIANA ISLANDS The 1996 Annual Tropical Cyclone Report is dedicated to: Captain Christopher 7. Nicklas, USA7 1967 to 1997

FRONT COVER: Vectors describe Typhoon Orson's (19W) surface wind field at approximately 01000Z September 1996. An automated algorithm, using the European Remote Sensing Satellite -1 (ERS-1) synthetic aperture radar (scatterometer) data, estimates these vectors which can be used to determine the radii of gale-force winds surrounding the typhoon. Although these data have proven invaluable, they are limited by the algorithm's inability to resolve scalar wind speeds above 50 knots and the wind direction 180 degree ambiguities.

U. S. NAVAL PACIFIC METEOROLOGY AND OCEANOGRAPHY CENTER WEST JOINT TYPHOON WARNING CENTER PSC 455, BOX 12 FPO AP 96540-0051

C. P. DILLON

CAPTAIN, UNITED STATES NAVY
COMMANDING OFFICER

MARK J. ANDREWS

LIEUTENANT COLONEL, UNITED STATES AIR FORCE DIRECTOR, JOINT TYPHOON WARNING CENTER





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STAFF

JOINT TYPHOON WARNING CENTER

LCDR	ERIC J. TREHUBENKO	USN	TDO, DEPUTY DIRECTOR
* LCDR	MICHAEL D. ANGOVE	USN	TDO, DEPUTY DIRECTOR
LCDR	KENNETH A. MALMQUIST	USN	TDO
** LCDR	STACY R. STEWART	USNR	TDO
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* LT	STEVEN P. DUARTE	USN	TDO
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CAPT	CHRISTOPHER T. NICKLAS	USAF	TDO
* CAPT	PAUL H. LEWIS	USAF	TDO, STATISTICS OFFICER
AG2	DARIN L. WARD	USN	LPO, GRAPHICS
AG3	JOHN E. UROGI	USN	TDA
* AG3	ROBERT M. GIGUERE	USN	TDA, STATISTICS
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SRA	SAMUEL R. PUGH	USAF	TDA
* SRA	JEFFREY L. WILKERSON	USAF	TDA
SRA	DIONNE M. TIRSCHEL	USAF	TDA
AIC	MARSHA D. BOGLE	USAF	TDA
A1C	JASON R. DOBBINS	USAF	TDA.

36 OSS/OSJ

MAJ	ROGER T. EDSON	USAF	TECHNIQUE DEVELOPMENT
CAPT	RICHARD A. ANSTETT	USAF	TDO, OIC USPACOM SAT NETWORK
* CAPT	JOHN A. RUPP	USAF	TDO, OIC USPACOM SAT NETWORK
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TSGT	SHIRLEY A. BROWN	USAF	CHIEF INFORMATION MANAGEMENT
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SSGT	MERRYRUTH I. DEOCARIZA	USAF	SAT FORECASTER
SSGT	LINDA R. HAM	USAF	SAT FORECASTER
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SSGT	BRUCE W. WOFFORD	USAF	SAT FORECASTER
SRA	SEAN M. McDUNN	USAF	DATA DEVELOPMENT

ATCR STAFF

CAPT	GARY B. KUBAT	USAF	TDO, EDITOR, BEST TRACK OFFICER
CAPT	WILLIAM J. CARLE	USAF	TDO, STATISTICS OFFICER
MR	FRANK H. WELLS	USN	TECHNICAL EDITOR
AG1	PAUL G. SANCHEZ	USN	LPO, GRAPHICS
AG2	BRYAN Y. HONG	USN	TDA, GRAPHICS
AG3	CHRISTOPHER CROSS	USN	TDA, GRAPHICS
A1C	MATHEW A. BOYD	USAF	TDA, GRAPHICS

UNIVERSITY OF GUAM / JTWC RESEARCH LIAISON

DR	MARK A. LANDER	TROPICAL CYCLONE RESEARCH, TECHNICAL WRITING
MR	CHARLES P. GUARD	TROPICAL CYCLONE RESEARCH, TECHNICAL WRITING

^{*} TRANSFERRED DURING 1996

^{**} ACTIVE DUTY TRAINING

FOREWORD

The Annual Tropical Cyclone Report is prepared by the staff of the Joint Typhoon Warning Center (JTWC), a combined Air Force/Navy organization operating under the command of the Commanding Officer, U.S. Naval Pacific Meteorology and Oceanography (NAVPACMETOCCEN Center West WEST)/Joint Typhoon Warning Center, Guam. The JTWC was founded 1 May 1959 when the U.S. Commander-in-Chief Pacific (USCINC-PAC) forces directed that a single tropical cyclone warning center be established for the western North Pacific region. The operations of JTWC are guided by USCINCPAC Instruction 3140.1W.

The mission of JTWC is multifaceted and includes:

- 1. Continuous monitoring of all tropical weather activity in the Northern and Southern Hemispheres, from 180° east longitude westward to the east coast of Africa, and the prompt issuance of appropriate advisories and alerts when tropical cyclone development is anticipated.
- 2. Issuance of warnings on all significant tropical cyclones in the above area of responsibility.
- 3. Determination of requirements for tropical cyclone reconnaissance and assignment of appropriate priorities.
- 4. Post-storm analysis of significant tropical cyclones occurring within the western North Pacific and North Indian Oceans.
- 5. Cooperation with the Naval Research Laboratory, Monterey, California on evaluation of tropical cyclone models and forecast aids, and the development of new techniques to support forecast requirements.

Special thanks to: the men and women of the Alternate Joint Typhoon Warning Center for standing in for JTWC as needed; Fleet Numerical Meteorology and Oceanography Center (FNMOC) for their operational support; the Naval Research Laboratory for its dedicated research; the Air Force Global Weather Central (AFGWC) and National Oceanic and

Atmospheric Administration (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) for satellite support; the 36th Squadron's Defense Communications Meteorological Satellite Program (DMSP) Site 18 at Nimitz Hill, Guam; and the Operations and Equipment Support departments of NAV-PACMETOCCEN WEST, Guam for their high quality support; all the men and women of the ships and facilities ashore throughout the JTWC area of responsibility (AOR), and especially on Guam, who took the observations that became the basis for our analyses, forecasts and postanalyses; CDR Lester E. Carr III and Dr. Russell L. Elsberry for their efforts at the Naval Postgraduate School and publication of the Systematic and Integrated Approach to Tropical Cyclone Track Forecasting Part II; the personnel at the Navy Publications and Printing Service Branch Office, Guam; Dr. Robert F. Abbey Jr. and the Office of Naval Research for their support to the University of Guam (UOG) for the Research Liaisons to JTWC; the UOG Research Liaisons for their contributions to this publication; Dr. Mark A. Lander for his training efforts, suggestions and valuable insights, and Mr. Charles P. Guard for his support and data collection efforts; Dr. Jeff D. Hawkins, Chris S. Veldon, Samuel Chang and Roger Weldon for their tireless efforts to get the most possible out of remote sensing technologies; Capt Carl Davis for his assistance in obtaining the satellite imagery for the northern Indian Ocean tropical cyclones; Mr. John "Jack" Beven for his efforts to include ground truth in his Weekly Tropical Cyclone Summaries; Mr. Charles R. "Buck" Sampson, Sally A. Calvert, Rosemary Lande, Mike D. Frost, Mugur Georgescu, Daren H. Grant, and Ann J. Schrader for their support and continued development of the Automated Tropical Cyclone Forecasting (ATCF) system; and, AG2 Bryan Y. Hong, AG3 Chris Cross, and A1C Matthew A. Boyd for their excellent desktop publishing and graphics assistance.

EXECUTIVE SUMMARY

The 1996 tropical cyclone season was spectacular. During the western North Pacific (WNP) season there was a near record number of significant tropical cyclones (TCs) -- 43 compared to the 1964 record of 44; 40% above average. Of these, 21 reached typhoon intensity -- the most typhoons in one season since 1972. Additionally, six reached supertyphoon intensity -- two above average. The north Indian Ocean (NIO) also experienced an active season with eight significant TCs -- 60% above average!

The Southern Hemisphere had an average season with 28 significant TCs, although the start of the 1997 season (coincident with the latter half of the 1996 Northern Hemisphere season) was more active than normal.

Despite the high ops tempo induced by an extremely active season, warning support to U.S. assets afield and afloat was superb. Warning verification statistics indicate JTWC was on par with the best season on record in terms of warning skill. The average 1996 forecast errors of 105 nm, 178 nm and 272 nm at 24-, 48- and 72-hour positions, respectively, were second only to 1994.

The JTWC continued to use and assist in the advancement of new technologies for the analysis and forecast of TCs during 1996. Satellite-measured observations of atmospheric winds from the ocean surface to the upper troposphere significantly contributed to earlier diagnosis of TC genesis and wind field definition. Examples include scatterometry-derived winds provided by the European Space Agency Remote Sensing Satellite (ERS-1&2), water vapor-, infrared-, and visible-derived drift wind vectors provided by the University of Wisconsin, and the Defense Meteorological Satellite Program's Special Sensor Microwave Imager-derived wind speed measurements.

Over 9500 satellite-based TC fixes were provided by the USPACOM Meteorological Satellite Network to support warnings in JTWC's Area of Responsibility (AOR), the bulk of which were provided by the JTWC Satellite Operations section. A new satellite-interpretation technique for TCs undergoing extratropical transition was developed in-house and used by the Network during 1996. Also developed during 1996 was systematic methodology to establish TC positions based on microwave imagery, and a new satellite-derived position code number criteria scheme.

The excellent error statistics of 1996 can in part be contributed to continued application of the Systematic and Integrated Approach to Tropical Cyclone Forecasting, developed by CDR Lester E. Carr III and Dr. Russell L. Elsberry of the Naval Postgraduate School. Also of note was the operational implementation of the Geophysical Fluid Dynamics - Navy (GFDN) model. GFDN is a slightly modified version of the model used by the National Hurricane Center for Atlantic TCs, and it provides guidance on selected TCs of tropical-storm or higher intensity throughout JTWC's AOR.

Another significant contribution to our overall error statistics has been the hard work and dedication of the "JTWC" team, consisting of Air Force and Navy officer, enlisted, and civilian personnel. Despite limited manning resources, JTWC met its mission objectives with flying colors. Unfortunately, with additional taskings such as the BRAC-directed move of the JTWC to Pearl Harbor in early 1999, the ability to support the production of a document such as this has been dramatically reduced. A significant reduction of scope in future Annual Tropical Cyclone Reports is planned, unless we hear differently from you, the reader.

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1. OPERATIONAL PROCEDURES

1.1 GENERAL

The Joint Typhoon Warning Center (JTWC) provides a variety of routine products and services to the organizations within its area of responsibility (AOR) as prescribed by USCINCPACINST 3140.1W. JTWC issues the following products:

- 1.1.1 SIGNIFICANT TROPICAL WEATHER ADVISORY Issued daily, or more frequently as needed, to describe all tropical disturbances and their potential for further development during the advisory period. Separate bulletins are issued for the Western Pacific and the Indian Oceans.
- 1.1.2 TROPICAL CYCLONE FORMATION ALERT Issued in a specified area when synoptic, satellite, or other germane data indicate development of a significant tropical cyclone is likely within 24 hours.
- 1.1.3 TROPICAL CYCLONE/ TROPICAL DEPRESSION WARNING Issued periodically throughout each day to provide forecasts of position, intensity, and wind distribution for tropical cyclones in JTWC's AOR.
- 1.1.4 PROGNOSTIC REASONING MES-SAGE Issued with warnings for tropical storms, typhoons, and super typhoons in the western North Pacific to discuss the rationale for the content of the specific JTWC warning.
- 1.1.5 PRODUCT CHANGES The contents and availability of the above JTWC products are set forth in USCINCPACINST 3140.1W. Changes to USCINCPACINST 3140.1W and JTWC products and services are proposed and discussed at the annual U.S. Pacific Command (PACOM) Tropical Cyclone Conference.

1.2 DATA SOURCES

- 1.2.1 COMPUTER PRODUCTS Numerical and statistical guidance are available from the USN Fleet Numerical Meteorology and Oceanography Center (FNMOC) at Monterey, California. FNMOC supplies JTWC with analyses and prognoses from the Navy Operational Global Atmospheric Prediction System (NOGAPS) via NIPRNET communication (refer also to section 1.3.5, TESS(3)). NOGAPS products routinely disseminated to JTWC include: surface pressure and winds, upper-air winds, deep-layer-mean winds, geopotential height and height change, and sea-surface temperature. These products are based on the 00Z and 12Z synoptic times, and atmospheric components are available at all standard levels. These products, along with selected ones from the (U.S.) National Center for Environmental Prediction (NCEP), the European Centre for Medium-Range Weather **Forecasts** (ECMWF), and the Japanese Meteorological Agency (JMA) are received as electronic files via networked computers, and by computer modem connections on government and commercial telephone lines as a backup method for the network. Additionally, selected computer generated products are received via the PC-Based Weather Facsimile (PCGRAFAX) System.
- 1.2.2 CONVENTIONAL DATA These data sets are comprised of land and shipboard surface observations, enroute meteorological observations from commercial and military aircraft (AIREPS) recorded within six hours of synoptic times, and cloud-motion winds derived from satellite data. The conventional data are manually and computer plotted, and manually analyzed in the tropics for the surface/gradient and 200-mb levels. These

analyses are prepared twice daily from 00Z and 12Z synoptic data.

1.2.3 SATELLITE RECONNAISSANCE — Meteorological satellite imagery recorded at USAF/USN ground sites and USN ships supply day and night coverage in JTWC's AOR. Interpretation of this satellite data provides tropical cyclone positions and estimates of current and forecast intensities (Dvorak, 1984). The USAF tactical satellite sites and Air Force Global Weather Central (AFGWC) currently receive and analyze Special Sensor Microwave/Imager (SSM/I) data to provide locations of tropical cyclones when the low-level center is obscured by higher clouds, and estimates of 35-kt (18-m/sec) wind radii near tropical cyclones.

Data from satellites — Defense Meteorological Satellite Program (DMSP), National Oceanographic and Atmospheric Administration (NOAA), (Japanese) Geostationary Meteorological Satellite (GMS), and (European Geostationary) Meteorological Satellite (METEOSAT) — provide the foundation for reconnaissance.

Use of satellite reconnaissance is discussed further in section 2.3 Satellite Reconnaissance Summary.

Additionally, scatterometry data from the European Remote Sensing (ERS)-1 satellite also provide valuable insight as to the distribution of low-level winds around tropical cyclones. This year's cover shows a scatterometer pass over Typhoon Orson (19W) from the ERS-1 satellite. When remotely sensed data of this quality became available, JTWC immediately began using it to supplement other available data. Evolution of algorithms and display of scatterometer data has occurred rapidly over the past few years and JTWC has been fortunate to have access to this leading edge technology.

JTWC retrieves scatterometry data on a routine basis from web sites on the

NIPRNET/Internet maintained by the Naval Oceanographic Office (NAVOCEANO), the Oceanic Sciences Branch of NOAA, and FNMOC. The scatterometry data available at these sites provide information on tropical cyclone position and low-level winds surrounding a tropical cyclone. Heavy-rain contamination near a tropical cyclone's center limits the usefulness of intensity estimation. In addition to determining positions and wind distribution around tropical cyclones, JTWC also uses scatterometry data to refine the twice daily manual analyses of the surface/gradient-level wind flow and atmospheric structure.

Scatterometry algorithms are discussed further in Chapter 7.

- 1.2.4 RADAR RECONNAISSANCE Land-based radar observations are used to position tropical cyclones. Once a well-defined tropical cyclone moves within range of land-based radar sites, radar reports are invaluable for determination of position, movement, and, in the case of Doppler radar, storm structure and wind information. JTWC's use of radar reports during 1996 is discussed in section 2.4 Radar Reconnaissance Summary.
- 1.2.5 AIRCRAFT RECONNAISSANCE Until the summer of 1987, dedicated aircraft reconnaissance was used routinely to locate and determine the wind structure of tropical cyclones. Now, aircraft fixes are only rarely available from transiting jet aircraft or from weather-reconnaissance aircraft involved in research missions. No aircraft fixes were available in 1996.
- 1.2.6 DRIFTING METEOROLOGICAL BUOYS In 1989, the Commander, Naval Meteorology and Oceanography Command (COMNAVMETOCCOM) put the Integrated Drifting Buoy Plan into action to meet

USCINCPACFLT requirements that included tropical cyclone warning support. In 1996, 30 drifting buoys were deployed in the western North Pacific by a NAVOCEANO-contracted C-130 aircraft. Of the 30 buoys, 24 were Compact Meteorological and Oceanographic Drifters (CMOD) with temperature and pressure sensors and six were Wind Speed and Direction (WSD) with wind speed and direction, temperature and pressure. The buoys were evenly split by type over two deployments — the first in June, followed by the second in September. The purpose of the split deployment was to overlap the expected threemonth lifespans of the CMOD buoys in order to provide continuous coverage during the peak of the western North Pacific tropical cyclone season.

1.2.7 AUTOMATED METEOROLOGICAL OBSERVING STATIONS (AMOS) — Through a cooperative effort between COMNAVMETOCCOM, the Department of the Interior, and NOAA/NWS to increase data availability for tropical analysis and forecasting, a network of 20 AMOS stations is being installed in the Micronesian Islands (see Tables 1-1 and 1-2). Previous to this effort. two sites were installed in the Northern Mariana Islands at Saipan and Rota through a joint venture between the Navy and NOAA/NWS. The site at Saipan relocated to Tinian in 1992. Since September of 1991, the capability to transmit data via Service ARGOS and NOAA polar-orbiting satellites has been available as a backup to regular data transmission to the Geostationary Operational Environmental Satellite (GOES) West, and more recently for sites to the west of Guam, to the GMS. Upgrades to existing sites are also being accomplished as opportunities arise to enable access to Service ARGOS. JTWC receives data from all AMOS sites via the AWN under the KWBC bulletin headers SMPW01, SIPW01 and SNPW01 (SXMY10 for Tinian and Rota).

1.3 TELECOMMUNICATIONS

Telecommunications support for the NPMOCW/JTWC is provided by the Naval ComputerTelecommunications Area Master Station, Western Pacific (NTWP) and their Base Communications Department. The NPMOCW/JTWC telecommunications link to NTWP is a new fiber-optic cable which incorporates stand-by redundancy features. Connectivity includes "switched" secure and non-secure voice, facsimile, data services, and dedicated audio and digital circuits to NTWP. Telecommunications connectivity and the basic system configurations which are available to JTWC follow.

1.3.1 AUTOMATED DIGITAL NETWORK (AUTODIN) — AUTODIN currently supports the message requirements for JTWC, with the process of converting to the new Defense Messaging System (DMS) in progress. A personal computer (PC) system running the "Gateguard" software application provides transmit and receive message capabilities. Secure connectivity is provided by a dial-up Secure Telephone Unit-III path with NTWP.

The Gateguard system is used to access the AUTODIN/DMS network for dissemination of warnings, alerts, related bulletins, and messages to Department of Defense (DoD) and U.S. Government installations. Message recipients can retransmit these messages for further dissemination using the Navy Fleet Broadcasts, Coast Guard continuous wave (CW) Morse code, and text to voice broadcasts.

AUTODIN/DMS messages are also relayed via commercial telecommunications routes for delivery to non-DoD users. Inbound message traffic for JTWC is received via AUTODIN/DMS addressed to NAVPACMETOCCEN WEST GU/JTWC.

Table 1-1 AUTOMATED METEOROLOGICAL OBSERVING STATIONS SUMMARY

Site	Location	enter de la companya de la companya La companya de la co	Call sign	ID#	<u>System</u>	<u>Installed</u>
Saipan*	15.2°N	145.7°E	15D151D2		ARC	1986
Rota	14.2°N	145.2°E	15D16448	91221	ARC	1987
Faraulep**	8.1°N	144.6°E	FARP2	52005	C-MAN/ARGOS	1988
Enewetak	11.4°N	162.3°E	ENIP2	91251	C-MAN/ARGOS	1989
Ujae***	8.9°N	165.7°E	UJAP2	91365	C-MAN	1989
Pagan	18.1°N	145.8°E	PAGP2	91222	C-MAN/ARGOS	1990
Kosrae	5.4°N	163.0°E	KOSP2	91355	C-MAN/ARGOS	1990
Mili	6.1°N	172.1°E	MILP2	91377	C-MAN	1990
Oroluk	7.6°N	155.2°E	ORKP2	91343	C-MAN	1991
Pingelap	6.2°N	160.7°E	PIGP2	91352	C-MAN/ARGOS	1991
Ulul	8.4°N	149.4°E	, NA	91328	C-MAN/ARGOS	1992
Tinian*	15.0°N	145.6°E	15D151D2	91231	ARC	1992
Satawan	6.1°N	153.8°E	SATP2	91338	C-MAN/ARGOS	1993
Ulithi	9.9°N	139.7°E	NA	91204	C-MAN/ARGOS	1995
Ngulu	8.3°N	137.5°E	NA	91411	C-MAN/ARGOS	1995
Ebon	4.6°N	168.7°E	NA.	91442	C-MAN/ARGOS	1996
Maloelap	8.7°N	171.2°E	NA ,	91374	C-MAN/ARGOS	1996

- * Saipan site relocated to Tinian and commissioned on 1 June 1992.
- ** The prototype site on Faraulep was destroyed on 28 November 1991 by Super Typhoon Owen.
- *** Ujae site was destroyed on 18 November 1992 by Super Typhoon Gay.

ARC = Automated Remote Collection system (via GOES West)

C-MAN = Coastal-Marine Automated Network (via GOES West or GMS)

ARGOS = Service ARGOS data collection (via NOAA's TIROS-N)

Table	1-2	PROPOSED	AUTOMATED	METEOROLOGICAL	OBSERVING	STATIONS

Site	Locatio	n	Installation	Delayed
Pulusuk	6.5°N	149.5°E	1993	Yes*
Faraulep	8.6°N	144.6°E	1994	Yes
Eauripik	6.7°N	143.0°E	1994	Yes
Utirik	11.2°N	169.7°E	1994	Yes
Satawal	7.4°N	147.0°E	1995	Yes
Ujelang	9.8°N	161.0°E	1995	Yes
Maug	20.0°N	145.2°E	1996	Yes

Runway construction

1.3.2 AUTOMATED WEATHER NET-WORK (AWN) — The AWN provides weather data over the Pacific Meteorological Data System (PACMEDS). JTWC uses two PC systems which run the Windows based WINDS/AWNCOM software application package to interface with a dedicated 1.2 kb/sec (kilo-bits per second) PACMEDS circuit. These PC systems provide JTWC the PACMEDS transmit and receive capabilities needed to effectively store and manipulate large volumes of alphanumeric meteorological data available from reporting stations throughout JTWC's AOR. The AWN also allows JTWC access to data which are available on the Global Telecommunications System (GTS). JTWC's AWN station identifier is PGTW.

1.3.3 AUTOMATED WEATHER DISTRIB-UTION SYSTEM (AWDS) — The AWDS consists of two dual-monitor workstations which communicate with a UNIX based communications/data server via a private Local Area Network (LAN). The server's data connectivity is provided by two dedicated long-haul data circuits. The AWDS provides JTWC with additional transmit and receive access to alphanumeric AWN data at Tinker AFB using a dedicated 9.6 kb/sec circuit. Access to satellite imagery and computer graphics from Air Force Global Weather Center (AFGWC) is provided by another dedicated 9.6 kb/sec circuit.

AWDS current configuration was upgraded in 1996 to include improved workstation performance, and integration into NPMOCW's LAN backbone which has access to the Defense Information Systems Network's (DISN), this and the NIPRNET connectivity should allow JTWC to send and receive products among other AWDS systems. Send e-mail requests to jtops@npmocw.navy.mil for more information.

1.3.4 DEFENSE SWITCHED NETWORK (DSN) — DSN is a worldwide, general purpose, switched telecommunications network for the DoD. The network provides a rapid and vital voice and data link for JTWC to communicate tropical cyclone information with DoD installations and civilian agencies.

JTWC utilizes DSN to access DSN-based users, FTS2000, SprintNET networks for commercial or non-DoD based users, and local commercial long distance carriers for voice and data requirements.

The DSN and commercial telephone numbers for JTWC are 349-5240 or 349-4224. The commercial area code is 671 and the DSN Pacific area code is 315.

1.3.5 TACTICAL ENVIRONMENTAL SUP-PORT SYSTEM (3) (TESS(3)) — The TESS(3) is connected by NIPRNET to FNMOC. NIPRNET connectivity is provided by a dedicated virtual-switched data services 56 kb/sec packet switched-data link. FNMOC's supercomputer generated gridded fields are pushed to the TESS(3) using NIPRNET, allowing for local value added tailoring of analyses and prognoses. The TESS(3) provides connectivity through NIPRNET to all COMNAVMETOCCOM Centers worldwide.

1.3.6 NIPRNET—DISN's NIPRNET has replaced the DDN MILNET computer communications network, providing a much needed boost in throughput speed for the transfer of large data and image files. NIPRNET has links or gateways to the non-DoD Internet, allowing data to be pulled and pushed from Internet based World Wide Web (WWW) and File Transfer Protocol (FTP) servers. This capability has enhanced JTWC's ability to exchange data with the Internet-based research community.

The JTWC's products are currently available to users of the DISN based Secret IP Router Network (SIPRNET) using WWW browser software. The JTWC's SIPRNET web site address can be obtained by contacting JTWC's Operations Officer. The JTWC's unclassified NIPRNET/Internet web site address is http://www.npmocw.navy.mil. The JTWC's Internet e-mail server's IP address is 192.231.128.1 and the e-mail address is jtops@npmocw.navy.mil.

1.3.7 TELEPHONE FACSIMILE—TELEFAX provides the capability to rapidly scan and transmit, or receive, documents over commercial telephone lines or DSN. TELEFAX is used to disseminate tropical cyclone advisories and warnings to key agencies on Guam and, in special situations, to DoD, other U.S. Government agencies, and the other Micronesian Islands. Inbound documents for JTWC are received at 349-6143, 349-6101, or 349-4032 (commercial area code 671, or DSN Pacific area code 315).

1.3.8 LOCAL USER TERMINAL (LUT) — JTWC uses a LUT, provided by the Naval Oceanographic Office, as the primary means of receiving real-time data from drifting meteorological buoys and ARGOS-equipped AMOS via the polar-orbiting TIROS-N satellites.

1.4 DATA DISPLAYS

1.4.1 AUTOMATED TROPICAL CYCLONE FORECAST (ATCF) SYSTEM — The ATCF is an advanced software program that assists the Typhoon Duty Officer (TDO) in the preparation, formatting, and dissemination of JTWC's products. It cuts message preparation time and reduces the number of corrections. The ATCF automatically displays: the working and objective best tracks; forecasts of track, intensity, and wind distribution; and,

information from computer generated forecast aids and products from other agencies. It also computes the myriad of statistics calculated by JTWC. Links have been established through the LAN to the NAVPACMETOC-CEN WEST Operations watch team to facilitate the generation of tropical cyclone warning graphics for the fleet facsimile broadcasts, for

NAVPACMETOCCEN WEST's local metwatch program, and for warning products for Micronesia. A module permits satellite reconnaissance fixes to be input from 36 OSS/OSJ into the LAN.

1.4.2 TESS(3) receives, processes, stores, displays and prints copies of FNMOC data and environmental products. It also ingests and displays satellite imagery from the Naval Meteorological Data Receiver-Recorder Set (SMQ-11) and other TESS(3) sets worldwide.

1.4.3 AWDS functions are similar to those of the TESS(3), but the environmental products and satellite global data base imagery are produced by AFGWC.

1.4.4 NAVAL OCEANOGRAPHIC DATA DISTRIBUTION SYSTEM (NODDS) — NODDS is a personal computer (PC)-based system that uses a telephone modem to download, store and display environmental and satellite products from FNMOC.

1.4.5 NAVAL SATELLITE DISPLAY
SYSTEM - GEOSTATIONARY (NSDS-G)
— The NSDS-G is NAVPACMETOCCEN
WEST's primary geostationary imagery processing and display system. It can be used to
process high resolution geostationary imagery
for analysis of tropical cyclone positions and
intensity estimates for the Western Pacific
Ocean should the Meteorological Imagery,
Data Display, and Analysis System (MIDDAS
- see Chapter 2) and Mark IVB (see Chapter
2 also) fail.

- 1.4.6 PC-BASED WEATHER FACSIMILE (PCGRAFAX) SYSTEM PCGRAFAX is a microcomputer-based system that receives, stores and displays analog and digital facsimile products that are transmitted over high frequency (HF) radio.
- SATELLITE WEATHER DATA 1.4.7 IMAGING SYSTEM (SWDIS) — The SWDIS (also known as the M-1000) is a PCbased system that interfaces with the LAN to retrieve, store, and display various products such as: geostationary-satellite imagery from other NSDS-G sites at Rota (Spain), Pearl Harbor (Hawaii), or Norfolk (Virginia), scatterometer data from NAVOCEANO and NOAA, and composites of global geostationary-satellite imagery from the Internet. The SWDIS has proven instrumental in providing METEOSAT reduced-resolution coverage of tropical cyclones over the western Indian Ocean as well as long time-series animations of water-vapor imagery.

1.5 ANALYSES

The JTWC TDO routinely performs manual streamline analyses of composite surface/gradient-level (3000 ft (914 m)) and upper-tropospheric (centered on the 200-mb level) data for 00Z and 12Z daily. Computer analyses of the surface, 925-, 850-, 700-, 500-, 400-, and 200-mb levels, deep-layer-mean winds, frontal boundaries depiction, 1000-200 mb/400-200 mb/and 700-400 mb wind shear, 500-mb and 700-mb 24-hour height change, and a variety of other meteorological displays come from the 00Z and 12Z FNMOC data bases. Additional sectional charts at intermediate synoptic times and auxiliary charts, such as station-time plot diagrams, time-height cross-section charts and pressure-change charts, are analyzed during periods of significant tropical cyclone activity.

1.6 FORECAST PROCEDURES

This section first introduces the Systematic and Integrated Approach to TC Track Forecasting by Carr and Elsberry (1994), referred to hereafter as the "Systematic Approach" and then provides JTWC's basic approach to track, intensity and wind radii forecasting.

- 1.6.1 THE SYSTEMATIC APPROACH JTWC began applying the Systematic Approach (Figure 1.1) in 1994. The basic premise of this approach is that forecasters can improve upon dynamical track forecasts generated by numerical models and other objective guidance if the forecasters are equipped with:
- 1) a meteorological knowledge base of conceptual models that organizes a wide array of scenarios into a relatively few recurring, dynamically-related situations; and
- 2) a knowledge base of numerical-model TC-forecast traits and objective-aid traits within the different recurring situations that is organized around the meteorological knowledge base.
- 1.6.1.1 General Concepts Track, intensity, and size components of a TC forecast are dynamically interdependent.
- 1) TC motion affects intensity and how a TC intensifies can affect its motion.
- 2) TC size affects propagation relative to environmental steering. A large TC may significantly modify its environment. Thus, the present size of a TC and any subsequent changes in size can affect motion.
- 3) TC size may affect intensity indirectly through changes induced on TC motion.
- 1.6.1.2 Key Motion Concepts TC motion results from a variety of causes.
- 1) Environmental Steering To a first approximation, TC's go where the winds of

the large scale environment blow them (i.e., TCs are a "cork in the stream").

- 2) TC Propagation The motion of TCs usually departs in a minor, but not insignificant way from the steering provided by the large scale environment.
- 3) TC-Environment Interaction In certain situations, the circulation of the TC interacts with the environment in such a way as to significantly alter the structure of the environment, thus modifying the environmental steering winds which are a primary source of TC motion.

1.6.1.3 Knowledge Base Framework

1.6.1.3.1 Environment Structure — Structure is classified in terms of a large-scale synoptic PATTERN and two or more synoptic REGIONs within the pattern that tend to produce characteristic directions and speeds of steering flow for a TC located therein. Four patterns with six associated regions are recognized by the Systematic Approach. JTWC notes that not all tropical cyclones fit "neatly" into these patterns/regions at all times and that hybrids and transitions between patterns

occur. These patterns/regions are briefly described below.

1.6.1.3.1.1 Patterns — There are four primary patterns:

Standard Pattern (S) (Figure 1.2)

- 1) most frequently occurring pattern in the WNP; and,
- 2) key feature is roughly zonally-oriented subtropical ridge (STR) anticyclones.

Poleward-Oriented Pattern (P) (Figure 1.3)

- 1) second highest frequency of occurrence in the WNP;
- 2) key feature is a ridge (anticyclone) that extends from the STR deep into the tropics and interrupts the tropical easterlies;
- 3) usually has SW-to-NE axis orientation; and,
- 4) usually produces strong poleward steering on its west and poleward side.

Monsoon Gyre (G) (Figure 1.4)

- 1) only occurs during June-November period;
- 2) key feature is a particularly large and deep monsoonal circulation (thus, "monsoon

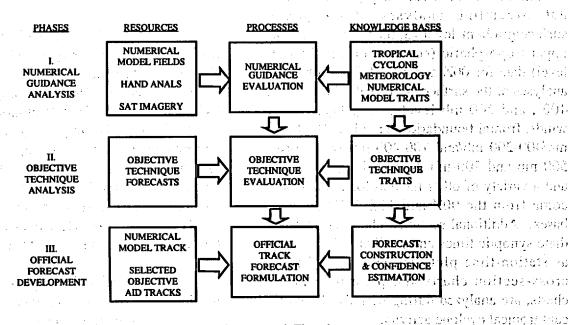


Figure 1.1 Systematic Approach Flowchart

gyre"); and,

3) usually situated between a zonally-oriented STR anticyclone to the NW and a meridionally-oriented anticyclone on its eastern periphery.

Multiple TC (M) (Figure 1.5)

- 1) key feature is more than one TC with a large break in the STR in the vicinity of the two TCs;
- 2) the TCs are oriented approximately east-west (i.e., zonally-oriented TCs);
- 3) the TCs must be far enough apart to preclude significant mutual advection, but close enough to preclude the development of ridging between them (typically greater than 10°, but less than about 25°);
- 4) the average latitude of the two TCs must be sufficiently close to the latitude of the STR axis (no more than about 10° equatorward or 5° poleward) so that regions of poleward/equatorward flow are established, which affect TC motion and intensification; and,
- 5) there are three subsets of the "M" pattern which describe varying degrees of interaction between the two cyclones.
- 1.6.1.3.1.2 Regions. There are six primary regions associated with the four patterns:

Dominant Subtropical Ridge (DR) — the area of tropical easterlies equatorward of the STR axis, except near any break in the STR;

Weakened Subtropical Ridge (WR) — the area of weaker southeasterly winds in the vicinity of a break in the STR;

Accelerating Midlatitude Westerlies (AW) — the area of eastward and poleward steering extending east from a break in the STR;

Poleward Oriented (PO) - the area of poleward steering west of the ridge feature in the "P" and "G" Patterns;

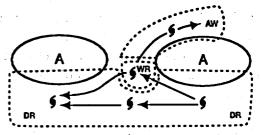


Figure 1.2 Standard Pattern

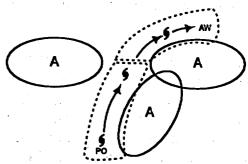


Figure 1.3 Poleward Oriented Pattern

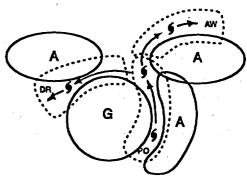
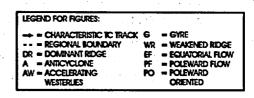


Figure 1.4 Gyre Pattern



Figure 1.5 Multiple TC Pattern



Multiple TC Poleward Flow (PF) — created in the region of the eastern TC of a "M" Pattern as a result of the gradient between the western TC and the STR circulation to the east; and,

Multiple TC Equatorward Flow (EF) — created in the region of the western TC of a "M" Pattern as a result of the gradient between the eastern TC and the STR circulation to the west.

- 1.6.1.3.1.3 Nomenclature. JTWC makes routine use of the aforementioned Patterns and Regions of the Systematic Approach. In order to quickly transcribe this information, a shorthand contraction standard has developed. By utilizing the one-letter contraction of a pattern and the two-letter contraction of an associated region (e.g., S/DR) an effective method of quickly and accurately describing Systematic Approach concepts in writing exists.
- 1.6.1.3.2 TC Structure. TC structure consists of an INTENSITY that is based on the maximum wind speed near the center of the TC, and a SIZE that is based on some measure of the extent of the TC windfield. TC intensity is related to steering level and TC size is related to propagation and environment modification.
- 1.6.1.3.3 Transitional Mechanism. These mechanisms act to change the structure of the environment (pattern/region) and fall into two categories:
- 1) TC-Environment Transformations. The TC and the environment may interact, resulting in a change in environmental structure (pattern/region) and thus the direction/speed of the associated steering flow. In addition, TC-environment transformations may result in a change to TC structure. Recognized TC-environment transformations are listed below (refer to Carr and Elsberry (1994) for a more

thorough treatment):

- Beta Effect Propagation
- Vertical Wind Shear
- Ridge Modification by TC
- Monsoon Gyre TC Interaction
- TC Interaction (Direct (DTI), Semidirect (STI), and Indirect (ITI)) (Figure 1.6)
- 2) Environmental Effects. These also result in changes to the structure of the environment (pattern/region) surrounding the TC, but do not depend on, are or largely independent of, the presence of the TC. Recognized environmental effects are listed below (refer to Carr and Elsberry (1994) for thorough treatment):
 - Advection by Environment
 - Monsoon Gyre Formation
 - Monsoon Gyre Dissipation
 - Subtropical Ridge Modulation (by midlatitude troughs)

TC movement, intensification, and size evolution are closely linked, therefore, an "ideal TC forecast approach" may be defined as a fully integrated solution for the time evolution of the 3-dimensional TC circulation. TC track, intensity and size forecasts are then to be considered as three partial representations of the total forecast solution.

1.6.2 BASIC APPROACH TO FORECASTING

1.6.2.1 Initial Positioning — The warning position is the best estimate of the center of the surface circulation at synoptic time. It is estimated from an analysis of all fix information received from one hour before to one and one-half hours after that synoptic time. The analysis is aided by a computer-generated objective best-track scheme that weights fix information based on its statistical accuracy. The TDO includes synoptic observations and other information to adjust the position, testing consistency with the past direction, speed of movement and the influence of the different scales of motions. If the fix data are not

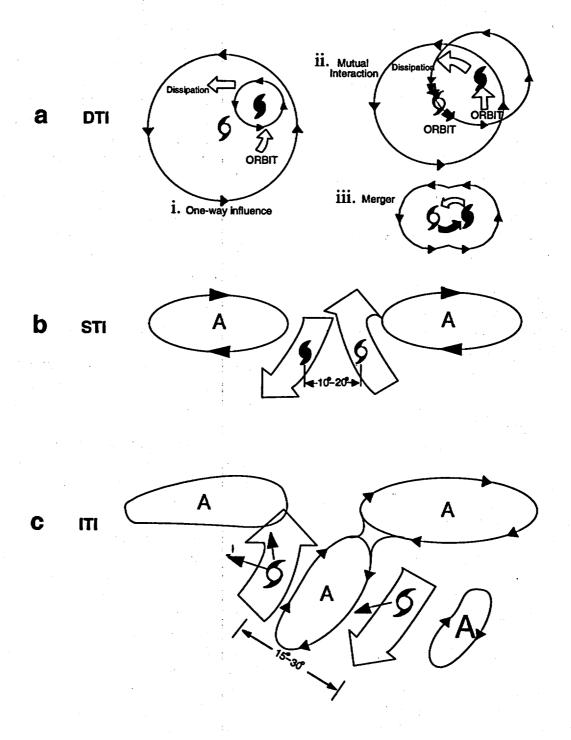


Figure 1-6 Tropical Cyclone Interaction: (a) Direct TC Interaction (DTI) is composed of three types — (i) one-way influence, (ii) mutual interaction, and (iii) merger — (b) Semi-Direct TC Interaction (STI), (c) and Indirect TC Interaction (ITI).

available due to reconnaissance-platform malfunction or communication problems, or are considered unrepresentative, synoptic data and/or extrapolation from previous fixes are used.

1.6.2.2 Track Forecasting — In preparing the JTWC official forecast, the TDO evaluates a wide variety of information and employs Systematic Approach methodology. The JTWC uses a standardized, three-phase tropical cyclone motion-forecasting process to improve forecast accuracy and forecast-to-forecast consistency. Figure 1.1 depicts the three phases and inputs to the Systematic Approach outlined below.

1.6.2.2.1 Numerical Guidance Analysis Phase — NOGAPS analyses and prognoses at various levels are evaluated for position, development, and movement of not only the tropical cyclone, but also relevant synoptic features such as:

- 1) subtropical ridge circulations;
- 2) midlatitude short/long-wave troughs and associated weaknesses in the subtropical ridge;
 - 3) monsoon surges;
- 4) influences of cyclonic cells in the tropical upper-tropospheric trough (TUTT);
 - 5) other tropical cyclones; and,
- 6) the distribution of sea-surface temperature.

The TDO determines into which pattern/region the tropical cyclone falls, and what environmental influences and transitional mechanisms are indicated in the model fields. The process outlined above permits the TDO to develop an initial impression of the environmental steering influences to which the tropical cyclone is, and will be, subjected to as depicted by NOGAPS. The NOGAPS analyses are then compared to the manually-plotted and analyzed charts prepared by the TDA and TDO, and to the latest satellite imagery, in order to determine how

well the NOGAPS-initialization process has conformed to the available synoptic data, and how well the resultant analysis fields agree with the synoptic situation inferred from the imagery. Finally, the TDO compares both the computer- and manually-analyzed charts to monthly climatology in order to make a preliminary determination of to what degree the tropical cyclone is, and will continue to be, subject to a climatological or nonclimatological synoptic environment. Noting latitudinal and longitudinal displacements of subtropical ridge and long-wave midlatitude features is of particular importance, and will partially determine the relative weights given to climatologically- or dynamically-based objective forecast guidance.

1.6.2.2.2. Objective Techniques Analysis Phase — By applying the guidance of the Systematic Approach, the TDO can relate the latest set of guidance given by JTWC's suite of objective techniques with the NOGAPS model prognoses and currently observed meteorological conditions. Performance characteristics for many of the objective techniques within the synoptic patterns/regions outlined in section 1.6.1.3.1.1 have been determined. Estimating the likely biases of each of the objective technique forecasts of TC track, intensity, and size given the current meteorological situation, the TDO eliminates those which are most likely inappropriate. The TDO also determines the degree to which the current situation is considered to be, and will continue to be, climatological by comparing the forecasts of the climatology-based objective techniques, dynamically-based techniques, and past motion of the present storm. Additionally, the spread of the set of objective forecasts, when plotted, is used to provide a measure of the predictability of subsequent motion, and the advisability of including a moderate-probability alternate forecast scenario in the prognostic reasoning message or warning (outside the western North Pacific).

The directional spread of the plotted objective techniques is typically small well before or well after recurvature (providing high forecast confidence), and is typically large near the decision point of recurvature or non-recurvature, or during a quasi-stationary or erratic-movement phase. A large spread increases the likelihood of alternate forecast scenarios.

- 1.6.2.2.3. Forecast Development Phase The TDO then constructs the JTWC official forecast giving due consideration to:
- interpretation of the TC-environment scenario depicted by numerical model guidance;
- 2) known properties of individual objective techniques given the present synoptic situation or geographic location;
- the extent to which the synoptic situation is, and is expected to remain, climatological; and,
- 4) past statistical performance of the various objective techniques on the current storm.

The following guidance for weighting the objective techniques is applied:

- 1) weight persistence strongly in the first 12 to 24 hours of the forecast period;
- 2) use conceptual models of recurring, dynamically-related meteorological patterns with the traits of the numerical and objectiveaid guidance associated with the specific synoptic situation; and,
- 3) give significant weight to the last JTWC forecast at all forecast times, unless there is significant evidence to warrant departure (also consider the latest forecasts from regional warning centers, as applicable).
- 1.6.3 INTENSITY FORECASTING The empirically derived Dvorak (1984) technique is used as a first guess for the intensity forecast. The TDO then adjusts the forecast after evaluating climatology and the synoptic situation. An interactive conditional-climatology scheme allows the TDO to define a situation

similar to the system being forecast in terms of location, time of year, current intensity, and intensity trend. Synoptic influences such as the location of major troughs and ridges, and the position and intensity of the TUTT all play a large part in intensifying or weakening a tropical cyclone. JTWC incorporates a checklist into the intensity-forecast procedure. Such criteria as upper-level outflow patterns, neutral points, sea-surface temperatures, enhanced monsoonal or cross-equatorial flow, and vertical wind shear are evaluated for their tendency to enhance or inhibit normal development, and are incorporated into the intensityforecast process. In addition to climatology and synoptic influences, the first guess is modified for interactions with land, with other tropical cyclones, and with extratropical features. Climatological and statistical methods are also used to assess the potential for rapid intensification (Mundell, 1990).

- 1.6.4 WIND-RADII FORECASTING Since the loss of dedicated aircraft reconnaissance in 1987, JTWC has turned to other data sources for determining the radii of winds around tropical cyclones. The determination of wind-radii forecasts is a three-step process:
- 1) Low-level satellite drift winds, scatterometer and microwave imager 35-kt windspeed analysis (see Chapter 2), and synoptic data are used to derive the current wind distribution.
- 2) The first guess of the radii is then determined from statistically-derived empirical wind-radii models. The JTWC currently uses three models: the Tsui model, the Huntley model, and the Martin-Holland model. The latter model uses satellite-derived parameters to determine the size and shape of the wind profile associated with a particular tropical cyclone. The Martin-Holland model also incorporates latitude and speed of motion to produce an asymmetrical wind distribution. These models provide wind-distribution

analyses and forecasts that are primarily influenced by the intensity forecasts. The analyses are then adjusted based on the actual analysis from step 1), and the forecasts are adjusted appropriately.

3) Finally, synoptic considerations, such as the interaction of the cyclone with mid-latitude high pressure cells, are used to fine-tune the forecast wind radii.

1.6.5 EXTRATROPICAL TRANSITION — When a tropical cyclone moves into the midlatitudes, it often enters an environment that is detrimental to the maintenance of the tropical cyclone's structure and energy-producing mechanisms. The effects of cooler sea-surface temperatures, cooler and dryer environmental air, and strong vertical wind shear all act to convert the tropical cyclone into an extratropical cyclone. JTWC indicates this conversion process is occurring by stating the tropical cyclone is "becoming extratropical." JTWC will indicate the conversion is expected to be complete by stating the system has become "extratropical." When a tropical cyclone is forecast to become extratropical, JTWC coordinates the transfer of responsibility with NAVPACMETOCCEN WEST which assumes

warning responsibility for the extratropical system.

1.6.6 TRANSFER OF WARNING RESPON-SIBILITY — JTWC coordinates the transfer of warning responsibility for tropical cyclones entering or exiting its AOR. For tropical cyclones crossing 180°E longitude in the North Pacific Ocean, JTWC coordinates with the Central Pacific Hurricane Center (CPHC), Honolulu via NAVPACMETOCCEN, Pearl Harbor, Hawaii. For tropical cyclones crossing 180°E longitude in the South Pacific Ocean, JTWC coordinates with NAVPACMETOCCEN, which has responsibility for the eastern South Pacific. Whenever a tropical cyclone threatens Guam, files are electronically transferred from JTWC to the Alternate Joint Typhoon Warning Center (AJTWC) collocated with NAVPACMETOCCEN. In the event that JTWC should become incapacitated, the AJTWC assumes JTWC's functions. Assistance in determining satellite reconnaissance requirements, and in obtaining the resultant data, is provided by the weather unit supporting the 15th Air Base Wing, Hickam AFB. Hawaii.

2. RECONNAISSANCE AND FIXES

2.1 GENERAL

JTWC depends primarily on two reconnaissance platforms, satellite and radar, to provide necessary, accurate and timely meteorological information in support of advisories, alerts and warnings. When available, synoptic and aircraft reconnaissance data are also used to supplement the above. As in past years, optimal use of all available reconnaissance resources to support JTWC's products remains a primary concern. Weighing the specific capabilities and limitations of each reconnaissance platform and the tropical cyclone's threat to life and property both afloat and ashore continues to be an important factor in careful product preparation.

2.2 RECONNAISSANCE AVAILABILITY

2.2.1 SATELLITE — Interpretation of satellite imagery by analysts at Air Force/Navy tactical sites and on Navy ships yields tropical cyclone positions, estimates of the current intensity and 24-hr forecast intensity. Additional positioning and surface wind field estimation information are available for analysis from DMSP SSM/I data and the ERS-2 and NSCAT scatterometers.

2.2.2 RADAR — Interpretation of land-based radar, which remotely senses and maps precipitation within tropical cyclones, provides positions in the proximity (usually within 175 nm (325 km)) of radar sites in Kwajalein, Guam, Japan, South Korea, China, Taiwan, Philippine Islands, Hong Kong, Thailand and Australia. Where Doppler radars are located, such as the Weather Surveillance Radar-1988 Doppler (WSR-88D) on Guam and Okinawa, measurements of radial velocity are also available, and observations of the tropical cyclone's horizontal velocity field and wind structure integrated in the vertical are possible.

2.2.3 AIRCRAFT — No weather reconnaissance aircraft fixes were received at JTWC in 1996.

2.2.4 SYNOPTIC — JTWC also determines tropical cyclone positions based on analysis of conventional surface/gradient-level synoptic data. These positions are an important supplement to fixes derived from remote sensing platforms, and become most valuable in situations where satellite, radar, and aircraft fixes are unavailable or are considered unrepresentative.

2.3 SATELLITE RECONNAISSANCE SUMMARY

Per **USCINCPAC** INSTRUCTION 3140.1W, the Pacific Air Force (PACAF) has primary responsibility for providing tropical cyclone reconnaissance for the U.S. Pacific Command (USPACOM). The Commanding Officer, NAVPACMETOCCEN WEST/JTWC, tasks all reconnaissance requirements, and the Officer In Charge (OIC) of the USPACOM Satellite Reconnaissance Network (hereafter referred to as Network) is delegated the authority to manage Network support to JTWC. However, operational control of radar and satellite readout sites engaged in tropical cyclone reconnaissance remains in normal command channels. The OIC of the Network and the personnel of Satellite Operations (SATOPS) are members of the 36 OSS/OSJ, and are collocated with JTWC at Nimitz Hill, Guam. The network sites are listed in Table 2-1.

Direct readout Network sites provide coverage of the tropical western North Pacific, South China Sea, and south central Indian Ocean using DMSP and NOAA TIROS polar orbiting satellites. PACAF Instruction 15-102 requires each network site to perform a minimum of two fixes per tropical cyclone per day if the tropical cyclone is within a site's coverage. Network

direct readout site coverage is augmented by other sources of satellite based reconnaissance.

Air Force Global Weather Central (AFGWC) provides AOR-wide coverage to

Table 2-1 USPACOM SATELLITE RECON	NAISSANCE
NETWORK SITES	
UNIT	ICAO
15 OSS/OSW, Hickam AFB, Hawaii	PHIK
18 OSS/OSW, Kadena AB, Japan	RODN
607 COS/DOW, Yongsan Garrison Republic of Korea	RKSY
Air Force Global Weather Central, Offutt AFB, Nebraska	KGWC
NPMOD DGAR, Diego Garcia	FJDG

JTWC using recorded smooth DMSP and NOAA TIROS imagery. This imagery is recorded and stored on the satellites for later relay to a command readout site, which in turn passes the data via satellite to AFGWC. Civilian contractors for the Army at Kwajalein Atoll provide additional polar orbiting satellite based tropical cyclone surveillance in the Marshall Islands and east of 180°W as needed. The NOAA/NESDIS Satellite Applications Branch at Suitland, Maryland (ICAO identifier KWBC) also performs tropical cyclone fix and intensity analysis over the JTWC AOR using METEOSAT and GMS geostationary platforms.

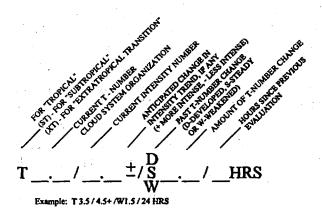


Figure 2-1 Dvorak code for communicating estimates of current and forecast intensity derived from satellite data. In the example, the current "T-number" is 3.5, but the current intensity is 4.5. The cloud system has weakened by 1.5 "T-numbers" since the evaluation conducted 24 hours earlier. The plus (+) symbol indicates an expected reversal of the weakening trend or very little further weakening of the tropical cyclone during the next 24-hour period.

The Network provides tropical cyclone positions and intensity estimates once JTWC issues either a TCFA or a warning. An example of the Dvorak code is shown in Figure 2-1. Each satellite-derived tropical cyclone position is assigned a Position Code Number (PCN) (Arnold and Olsen, 1974), which is a statistical estimate of fix position accuracy. The PCN is determined by 1) the availability of visible landmarks in the image that can be used as references for precise gridding, and 2) the degree of organization of the tropical cyclone's cloud system (Table 2-2)

Once a tropical cyclone reaches an intensity of 50 kt (26 m/sec), AFGWC and Nimitz Hill SATOPS analyze the 35-kt (18-m/sec) wind dis-

Table 2-2 POSITION CODE NUMBER (PCN)

PCN CENTER DETERMINATION/GRIDDING METHOD

- 1 EYE/GEOGRAPHY
- 2 EYE/EPHEMERIS
- 3 WELL DEFINED CIRCULATION CENTER/GEOGRAPHY
- 4 WELL DEFINED CIRCULATION CENTER/EPHEMERIS
- 5 POORLY DEFINED CIRCULATION CENTER/GEOGRAPHY
- 6 POORLY DEFINED CIRCULATION CENTER/EPHEMERIS

tribution surrounding the tropical cyclone based on microwave satellite imagery.

SATOPS provides three-hourly positions and six-hourly intensity estimates for all tropical cyclones in TCFA or warning status. Current intensity estimates are made using the Dvorak technique for both visible and enhanced infrared imagery. The standard relationship between tropical cyclone "T-number", maximum sustained surface wind speed, and minimum sea-level pressure (Atkinson and Holliday, 1977) for the Pacific is shown in Table 2-3. Subtropical cyclone intensity estimates are made using the Hebert and Poteat (1975) technique. Intensity estimates of tropical cyclones undergoing extratropical transition are made

using the Miller and Lander (1997) technique described in section 2.3.3.

SATOPS at Nimitz Hill uses hourly full disk GMS imagery to observe 70% of the JTWC AOR from 80°E to 180°W (Figure 2-2). Images are remapped to a Mercator projection

Table 2-3 ESTIMATED MAXIMUM SUSTAINED WIND SPEED (KT) AS A FUNCTION OF DVORAK CURRENT AND FORECAST INTENSITY NUMBER AND MINIMUM SEA-LEVEL PRESSURE (MSLP)

AND MINIMUR	1 JER-BE	VED PRESSURE	(MSDF)
100	ESTIM	ATED WIND	MSLP (MB)
T-NUMBER	SPEED-	-KT (M/SEC)	(PACIFIC)
0.0	<25	< (13)	
0.5	25	(13)	
1.0	25	(13)	
1.5	25	(13)	-,
2.0	30	(15)	1000
2.5	35	(18)	997
3.0	45	(23)	991
3.5	55	(28)	984
4.0	65	(33)	976
4.5	77	(40)	966
5.0	90	(46)	954
5.5	102	(53)	941
6.0	115	(59)	927
6.5	127	(65)	914
7.0	140	(72)	898
7.5	155	(80)	879
8.0	170	(87)	858

to enhance imagery limb coverage at 80°E - 100°E. Animated geostationary imagery is a valuable tool for determining the location and motion of tropical cyclones. Animated water vapor channel imagery is useful for observing environmental synoptic features that affect tropical cyclone development and movement.

SATOPS has access to polar and geostationary data on both the Air Force Mark IVB workstation and the MIDDAS. The MIDDAS consists of a network of three DEC Vax 3400s running advanced graphics software, with two large screen workstations. The Mark IVB is the SATOPS backup satellite data analysis system with the ability to ingest and process both polar and geostationary satellite data, and display imagery on one large screen workstation. The Mark IVB also acts as a front end for the MIDDAS which has no independent receiver/anten-

na. Both the MIDDAS and the Mark IVB can display NOAA Advanced Very High Resolution Radiometer (AVHRR), DMSP Operational Linescan System (OLS) and Special Sensor Microwave/Imager (SSM/I), and also geostationary visible, infrared and water vapor channel imagery. The MIDDAS can display NOAA TIROS Operational Vertical Sounder (TOVS) data, and the Mark IVB can display DMSP SSM/T1 and SSM/T2 sounder data.

NOAA TIROS AVHRR imagery provides five channels of imagery — visible, near and middle IR, and two in the far IR channels. DMSP OLS provides imagery in two channels — visible/near IR (commonly referred as broadband visible), and far IR. TOVS includes the High Resolution Infrared Radiation Sounder/2 (HIRS/2), the Microwave Sounding Unit (MSU), and the Stratospheric Sounding Unit (SSU).



Figure 2-2 GMS Full Disk Coverage

2.3.1 SATELLITE PLATFORM SUMMARY—Figure 2-3 shows the operational status of polar orbiting spacecraft. Imagery was received from two DMSP and two NOAA satellites during 1996. Both of the F-10 and F-11 OLS imagers are in standby mode and only SSM/I imagery was provided, while F-12 provided only OLS imagery. Only F-13 provided both OLS and SSM/I imagery. NOAA-12 and NOAA-14 were operational throughout the year, with fully functional AVHRR imagers.

2.3.2 STATISTICAL SUMMARY—Satellite-based tropical cyclone positions and intensities were the primary input for JTWC's warnings, accounting for 91% of all fixes. The Network and other agencies provided JTWC with 10,360 fixes — 5,568 western North Pacific, 629 northern Indian Ocean, 2,539 Southern Hemisphere, and 1,624 for circulations which did not develop into significant tropical cyclones. JTWC SATOPS provided 7,601 of the fixes. A comparison of satellite fixes to corresponding best track positions is shown in Table 2-4.

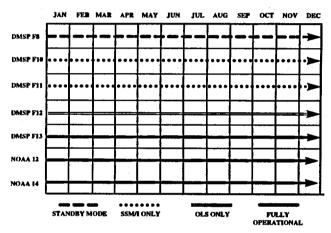


Figure 2-3 Polar orbiting spacecraft status for 1996

2.3.3 APPLICATION OF NEW TECHNIQUES AND TECHNOLOGY—SATOPS uses animated geostationary imagery, multispectral display capability, and microwave imagery to assign fix codes to each tropical cyclone pattern and sensor type (see Table 2-5) (Crume and Lander, 1997). These fix codes will be compared to best track positions to reexamine JTWC's use of the current PCNs after sufficient data are collected. The goal is to give the TDO a better statistical value for each satellite-derived fix position based on the use of current sensors. Many of our current sensors were not operational during the original PCN study.

In addition, SATOPS developed an XT technique (Miller and Lander, 1997a) to better esti-

mate the intensity of tropical cyclones undergoing extratropical transition — a weakness in the current Dvorak technique. The Dvorak T numbers appear to drop too fast when such systems

Table	2-4 ME	AN DEVIATION	ON (NM)	OF ALL D	MSP				
NETWORK DERIVED TROPICAL CYCLONE POSITIONS									
ŀ	FROM JTWC BEST TRACK POSITIONS								
1 .	(NUMBER OF CASES IN PARENTHESES)								
i									
		NORTH PAC							
PCN	1986-199	5 AVERAGE	1996	AVERAGE					
162	13.9	(7239) (6714)	11.4	(1,155)					
3 & 4	23.7	(6714)	26.9	(813)					
5&6	41.2	(16,793)	54.7	(2,698)					
Totals	30.9	(30,746)	39.2	(4,666)					
		RTH INDIAN							
PCN	1986-199	5 AVERAGE	1996	<u>AVERAGE</u>					
162	12.8	(164) (151)	15.3	(7)					
3&4	31.9	(151)	25.3	(70)					
5&6	39.2	(1,364)	53.9	(459)					
	,								
Totals	36.0	(1,679)	49.7	(536)					
1									
		CIFIC AND			EAN				
PCN	<u>1986-199</u>	AVERAGE	1996	<u>AVERAGE</u>					
162	15.7	(2,514)	11.2	(337)					
3&4	25.9	(2,514) (2,004)	24.7	(338)					
5&6	36.5	(9,209)	35.9	(1,379)	j				
l:					ļ				
Totals	31.1	(13,727)	30.0	(2,054)					

lose their persistent central convection, while synoptic data indicate the low-level circulations still contain winds greater than what is indicated by the T numbers. The XT technique should be applied during intensity analysis when a tropical cyclone:

- 1) loses one half or more of its persistent central convection:
- 2) maintains its forward motion, or accelerates; or,
- 3) when it undergoes compound or complex transition.

The XT technique should be applied as soon as appropriate to avoid an artificial intensity minima and discontinued after extratropical transition is complete. Transition is defined as complete when the system has progressed poleward of the polar jet maximum or when water-

vapor imagery clearly indicates the core of the system has become very dry. After extratropical transition is complete, the intensity estimation technique of Smigielski and Mogil (1992) for midlatitude cyclones is more appropriate.

Satellite imagery features measured with the XT technique are:

- 1) Arc length of the primary outer cloud band not connected with the circulation center.
- 2) organizational extent of the low-level circulation.
- 3) existence of deep convection between the outer cloud band and the circulation center.

4) translational speed of the system. (Refer also to Figure 2-4.)

Table 2-6 shows the wind intensities associated with each XT number, which are on the same wind scale as Atkinson and Holliday (1977).

Work is underway at SATOPS to establish methodology for determining tropical cyclone center positions from SSM/I imagery (Miller and Lander, 1997b). SATOPS produced 511 SSM/I-based fixes in 1996 with the MISTIC. Timeliness and number of SSM/I-based fixes should continue to improve with the network

PCN	PCN	Definitions	OM SATELLITE (NOTE 1) Sensor /technique type and fix code						
Grid	Grid	Definitions	IR	Vis	Both	SSM/I	Vis/IR	Anmto	
by	by		I IK	A 12	Dom		VIS/IK		
Geography	Ephemeris				•	only (note 3)	SSM/I	(note 4)	
(note 2)	(note 2)					(Hote 3)	(note 3)		
1	2	EYE	L		L	<u> </u>	(Hole 3)		
		Eye within CDO, geometric center	1	2	3	4	s	A	
*		(regular/round, any diameter)	'		,	7	"	Α.	
		(note 5)	**	,					
		Small eye (irregular/ragged, diameter	5	6	7	8	s	A	
		< 30 nm on long axis) (note 5)		ľ		0		Α.	
3	4	WELL DEFINED	·	<u> </u>					
		Eye(ragged/irregular, diameter	9	10	11	12	s	A	
		> 30 nm center more than 1/2			••		"		
		enclosed by wall cloud) (note 5)							
		Tightly curved band/banding type	13	14	15	16	s	A	
		eye (band curves at least 1/2 distance	"	• •		10		^	
		around center, diameter ≤ 90 nm)							
		Exposed low-level CC	17	18	19	20	s	A	
		Small CDO (round with well		21	22	23	s	A	
		defined edges, positioned near							
		geometric center, diameter ≤ 80 nm)					l		
		Small embedded center (diameter	24		25	26	s	A	
		≤ 80 nm)					į		
		Large CDO (with clear		27	28	29	S	A	
		indications of shearing, low-level					ľ		
		cloud lines, or overshooting tops,							
		that bias low-level center				. [
		position away from the geometric					1		
		center, diameter > 80 nm)							
		Any CDO or Embedded Center	30	31	32	33	S		
		with low-level CC clearly visible					i		
		on co-registered SSM/I (note 6)					l l		

5	6	POORLY DEFINED CC						
		Large eye (ragged/irregular, dia-	34	35	36	37	S	A
		meter > 30 nm on long axis, more						
		than 1/2 enclosed by wall cloud)						
		Spiral banding systems (convective	38	39	40	41	S	A
l		curvature) not classifiable as						
ŀ		banding eye or tightly curved band						
		Large CDO	42	43	44	45	S	A
		Embedded center positioned with IR	46		A			
		Partially exposed low-level centers	47	48	49	50	S	A
		with CC less than 1/2 exposed						
		Cloud minimum wedge/cold comma	51	52	53	54	S	Α
		Central cold cover	55	56	57	58	S	A
		Cirrus outflow (upper-level outflow	59	60	61	62	S	A
		provides the only circulation						
		parameters)						
		Poorly organized low-level center	63					
		evident only in high resolution						
		animation (Vis/IR or both)						
		All others	64	65	66	67	S	A
ļ		Monsoon depressions or multiple	Any combination of Vis, IR/EIR, and SSM/I					
		cloud clusters, positioned using any						
		of the following methods:						
		Circle method	68					
		Conservative feature	69					
		Animation	70					
		Extrapolation	71					

Note 1: Use the following steps to determine the PCN and Fix Code:

- a. Based on the analysis of the circulation parameters, determine a TC low-level CC position.
- b. Go to Table 2-5, then to the definitions column. Choose a PCN based on the cloud pattern, discrete measurements, as necessary, and/or technique used to determine the position.
- c. Move across to the Fix Code columns, and based on the sensor(s) used, select a fix code.

Note 2: Odd PCNs (1, 3, 5) are gridded with geography, the low-level CC being within 10 degrees (600 nm) of the geographic feature used for gridding. Even PCNs (2, 4, 6) are gridded with ephemeris, or the low-level CC is not within 10 degrees (600 nm) of the geographic feature used for gridding.

Note 3: Append "S" to the numerical fix code entry to indicate Special Sensor Microwave Imager (SSM/I) and visible and/or IR data was used in determining the low-level CC (i.e. 18S). (DMSP) fixes only. For the purposes of this fix code, SSM/I (S) and Animation (A) are mutually exclusive.

Note 4: Append "A" to the numerical fix code entry to indicate animation was used in determining the low-level CC (e.g. 11A). Geostationary fixes only. For the purposes of this fix code, SSM/I (S) and Animation (A) are mutually exclusive.

Note 5: For fix code entries 1-9, encode 01-09.

Note 6: In order to use SSM/I data to position low-level CCs, you must be able to correct the navigation/gridding and interrogate the SSM/I imagery directly for latitude/longitude (DMSP fixes only).

using DMSPs F10 and F11 (SSM/I-only) on the Mark IVB. The recently successful F14 launch should also enhance JTWC's use of the microwave products during 1997.

Mark IVB Network sites received the new software Build 7 during 1996. Also installed

Tal	10	2	2 - 6	XT	- INTENSI	ri Es
77	KT	_	хт	4.5	т 4.	5
65	KT	-	XT	4.0	Т 4.	0
55	KT	-	XT	3.5	т 3.	5
45	KT	-	XT	3.0	т 3.	0
35	KT	-	XT	2.5	т 2.	5
30	KT	-	XT	2.0	т 2.	0
25	КT	-	XT	1.0	T 1.	5
20	KT	-	XT	0.0	T 1.	.0

was a patch which allows navigation of SSM/I imagery and the ability to overlay SSM/I and OLS imagery. In addition, installation of the Mark IVB Satellite Imagery Dissemination System (SIDS) was completed at Kadena AB and Nimitz Hill SATOPS. SIDS generates satellite imagery products from the Mark IVB, and makes them available to geographically separated units via modem dial-up or LAN/Server connections.

2.3.4 FUTURE OF SATELLITE RECONNAIS-SANCE — SATOPS remains committed to improving the support provided to JTWC and the USPACOM tropical cyclone warning system. The most significant METSAT improvement anticipated in 1997 is the summer launch of the Chinese geostationary satellite, Feng Yun. With a subpoint at 105°E, this satellite will offer a field of view over the Indian Ocean extending to the east coast of Africa (Figure 2-5). Network sites in the western Pacific should be able to access real time imagery from both GMS-5 and Feng Yun-2B. This opportunity will also provide JTWC with total geostationary satellite coverage of its AOR for the first time.

HQ PACAF/DOW and the Mark IVB depotsupport team are exploring a means to send

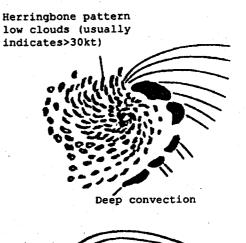




Figure 2-4 Two examples of cloud features analyzed with the XT Technique.

DMSP high resolution and SSM/I imagery to JTWC after the Base Realignment and Closure (BRAC) mandated relocation to Pearl Harbor, Hawaii (planned for January, 1999). Transmission of Feng Yun 2 geostationary data to Pearl Harbor is being addressed since this satellite will orbit below the horizon at Hawaii preventing line of sight communication.



Figure 2-5 Geostationary coverage from 105°E

Mark IVB software Build 8 will introduce a more user-friendly menu and the ability to generate common image files, such as bitmaps, GIF or TIFF files, from received satellite imagery. Installation of the DMSP Image Generating System (DIGS) on the MISTIC II workstation allows SATOPS to save SSM/I imagery in TIFF files.

AFGWC recently implemented a new capability to use geostationary data from METEOSAT, GMS, and GOES to provide additional fix support. In addition, DMSP F-14 was launched in April 1997 in anticipation of DMSP F-12's failure and should provide valuable data. A Dvorak-like technique is under development to determine tropical cyclone intensity from SSM/I imagery.

2.4 RADAR RECONNAISSANCE SUMMARY

Of the 43 significant tropical cyclones in the western North Pacific during 1996, 17 passed within range of land-based radar with sufficient precipitation and organization to be fixed. A total of 691 land-based radar fixes were logged at JTWC. As defined by the World Meteorological Organization (WMO), the accu-

racy of these fixes falls within three categories: good [within 10 km (5 nm)], fair [within 10 - 30 km (5 - 16 nm)], and poor [within 30 - 50 km (16 - 27 nm)]. Of the 691 radar fixes encoded in this manner, 182 were good, 239 fair, and 270 poor. The radar network provided timely and accurate fixes which allowed JTWC to better track and forecast tropical cyclone movement. In addition to fixes, the Guam and Okinawa WSR-88D radars supplied meteorologists with a look into the vertical and horizontal structure of precipitation and winds in tropical cyclones passing nearby.

In the Southern Hemisphere, 50 radar reports were logged for tropical cyclones. No radar fixes were received for the North Indian Ocean.

2.5 TROPICAL CYCLONE FIX DATA

Table 2-7a delineates the number of fixes per platform for each individual tropical cyclone for the western North Pacific. Totals and percentages are also indicated. Similar information is provided for the North Indian Ocean in Table 2-7b, and for the South Pacific and South Indian Ocean in Table 2-7c.

01W TD 02W TS ANN 03W TD 04W TY BART 05W TS CAM 06W TY DAN 07W STY EVE 08W TY FRANKII 09W TY GLORIA 10W STY HERB 11W TS IAN 12W TY JOY 13W TY KIRK	122 268	0 0 0 8 2 3 1 0	0 5 0 7 0 9 88	0 3 0 0 1 0	0 0 0 0 0	53 170 11 256 93 186
03W TD 04W TY BART 05W TS CAM 06W TY DAN 07W STY EVE 08W TY FRANKI 09W TY GLORIA 10W STY HERB 11W TS IAN 12W TY JOY	11 241 90 174 253 85 122 268	0 8 2 3 1 0	0 7 0 9 88	0 0 1 0	0 0 0	11 256 93
04W TY BART 05W TS CAM 06W TY DAN 07W STY EVE 08W TY FRANKI 09W TY GLORIA 10W STY HERB 11W TS IAN 12W TY JOY	241 90 174 253 85 122 268	8 2 3 1 0	7 0 9 88	0 1 0	0 0	256 93
05W TS CAM 06W TY DAN 07W STY EVE 08W TY FRANKI 09W TY GLORIA 10W STY HERB 11W TS IAN 12W TY JOY	90 174 253 85 122 268	2 3 1 0	0 9 88	1 0	0	93
06W TY DAN 07W STY EVE 08W TY FRANKI 09W TY GLORIA 10W STY HERB 11W TS IAN 12W TY JOY	174 253 85 122 268	3 1 0 0	9 88	0	0	
07W STY EVE 08W TY FRANKII 09W TY GLORIA 10W STY HERB 11W TS IAN 12W TY JOY	253 85 122 268	1 0 0	88	-	_	186
08W TY FRANKII 09W TY GLORIA 10W STY HERB 11W TS IAN 12W TY JOY	85 122 268	0 0		11		
09W TY GLORIA 10W STY HERB 11W TS IAN 12W TY JOY	122 268	0	0		0 .	353
10W STY HERB 11W TS IAN 12W TY JOY	268			5	0	90
11W TS IAN 12W TY JOY		_	37	8	0	167
12W TY JOY		1	25	8	0	302
	53	0	· O	0	0	53
13W TY KIRK	183	1	0	0	0	184
	348	2	220	5	0	575
14W TS LISA	48	0	9	2	0	59
15W TD	57	1	0	0	0	58
16W TS MARTY	20	1	0	6	0	27
17W TD	16	0	0	0	0	16
18W TY NIKI	142	1	3	4	0	150
19W TY ORSON	321	3	. 0	0	0 -	324
20W TY PIPER	97	2	0	Ō	0	99
21W TD	26	0	0	0	0	26
22W TS RICK	68	2	0	Ô	0	70
23W STY SALLY	148	1	16	1	Ö	166
24W TS	68	0	0	3	Ō	71
25W TY TOM	165	3	0	3	Ō	171
26W STY VIOLET	222	5	21	1	0	249
27W TY WILLIE	81	0	13	5	Ō	99
28W STY YATES	230	1	46	0	Ŏ	277
29W TY ZANE	243	2	153	ĭ	Ŏ	399
30W TS ABEL	153	4	0	5	Ö	162
BIW TD	91	0	0	0	Ö	91
32W TY BETH	209	3	10	2	Ō	224
33W TY CARLO	171	3	0	1	Ö	175
34W TD	19	2	Ō	3	Ŏ	24
35W TS	31		Ō	4	Ŏ	36
36W STY DALE	189	7	23	0	Õ	219
37W TS ERNIE	234	i	6	8	ŏ	249
38W TS	50	Ö	ŏ	Ö	Ŏ	50
39W TD	18	2	Ö	5	ŏ	25
40W TD	83	4	Ö	2	ŏ	89
IW TD	57	i	ŏ	ō	ŏ	58
2W TY FERN	216	4	ŏ	6	ŏ	226
3W TS GREG	52	1	ŏ	ő	Ö	53
Totals	5,568	73	691	103	0	6,435

FROPICAL CYCLONE	SATELLITE	<u>SCATTEROMETER</u>	RADAR	SYNOPTIC	AIRCRAFT	TOTAL
01 B	54	1	0	0	0	55
02A	10	1	0	0	0	11
03 B	96	. 0	. 0	. 6	0	102
04A	25	0	0	0	0	25
05A	85	3	0	16	0	104
06B	114	i	0	2	0	117
0 7B	87	0	0	1	0	88
08B	158	2	0	1	0	161
Fotals	629	8	0	26	0	663

02S EMMA	TROPICAL CYCLONE	SATELLITE	SCATTEROMETER	RADAR	SYNOPTIC	AIRCRAFT	TOTAL
03S FRANK	01S DARYL/AGNIELLE	185	1	0	0	0	186
04S GERTIE 97 1 5 1 0 10 05P BARRY 76 0 2 0 0 0 7 06S BONITA 81 1 0 0 3 0 0 07S HUBERT/CORYNA 71 1 0 0 0 0 0 7 08P YASI 33 0 0 0 0 0 0 0 0 0 08P YASI 33 0 0 0 0 0 0 0 0 0 09P CELESTE 76 0 5 2 0 0 8 10P JACOB 175 0 0 0 4 0 17 1IS ISOBEL 66 1 0 0 0 0 0 0 0 0 12S 64 0 0 0 0 0 0 0 0 0 13P DENNIS 128 1 22 0 0 0 13 14S DOLORESSE 44 3 0 0 0 0 0 0 4 15S 28 1 2 0 0 0 3 16S EDWIDGE 61 1 0 0 0 0 0 0 0 17S FLOSSY 47 0 0 0 0 0 0 0 0 18S KIRSTY 98 0 11 1 0 0 0 0 18S KIRSTY 98 0 11 1 0 11 19P ETHEL 93 1 9 1 0 10 20P ZAKA 13 0 0 0 0 0 0 0 21P ATU 57 1 1 1 2 0 0 0 22S GUYLIANNE 47 2 0 0 0 0 4 24S HANSELLA 56 4 0 0 0 0 0 0 25S OLIVIA 138 2 0 0 0 0 12 24S HANSELLA 56 4 0 0 0 0 0 12 25S OLIVIA 138 2 0 0 0 0 12 27S 110 0 0 0 0 0 0 12 28S JENNA 121 0 0 0 0 0 0 12	02S EMMA	168	2	0	0	0	170
05P BARRY 76 0 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	03S FRANK	144	1	13	1	0	159
06S BONITA 81 1 0 3 0 8 07S HUBERT/CORYNA 71 1 0 17 0	04S GERTIE	97	i	5	1	0	104
07S HUBERT/CORYNA 71 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	05P BARRY	76	0	2	0	0	78
08P YASI 33 0 0 0 0 0 0 20 20 0 0 0 0 0 0 0 0 0	06S BONITA	81	1	0	3	0	85
09P CELESTE 76 0 5 2 0 8 10P JACOB 175 0 0 4 0 17 11S ISOBEL 66 1 0 0 0 0 6 12S 64 0 0 0 0 0 6 6 1 0 0 0 0 0 13 13 14 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 13 0	07S HUBERT/CORYNA	71	1	0	0	0	72
10P JACOB 175 0 0 4 0 175 11S ISOBEL 66 1 0 0 0 0 0 12S 64 0 0 0 0 0 0 0 13P DENNIS 128 1 2 0 0 0 0 13 14S DOLORESSE 44 3 0 0 0 0 4 4 15S 28 1 2 0 0 0 4 4 4 0	08P YASI	33	0	0	0	0	33
11S ISOBEL 66 1 0 0 0 6 12S 64 0 0 0 0 0 0 13P DENNIS 128 1 2 0 0 13 14S DOLORESSE 44 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	09P CELESTE	76	0	5	2	0	83
12S	IOP JACOB	175	0	0	4	0	179
13P DENNIS 128 1	IIS ISOBEL	66	1	0	0	0	67
14S DOLORESSE 44 3 0 0 0 4 15S 28 1 2 0 0 3 16S EDWIDGE 61 1 0 0 0 0 6 17S FLOSSY 47 0 0 0 0 0 0 4 18S KIRSTY 98 0 11 1 0 11 1 0 11 1 0 11 1 0 10 10 10 10 10 10 10 11 1 0 10 10 10 10 10 11 1 0 11 11 11 11 11 11 11 10	125	64	• 0	0	0	0	64
15S 28 1 2 0 0 3 16S EDWIDGE 61 1 0 0 0 0 0 0 17S FLOSSY 47 0 0 0 0 0 0 0 0 0 0 11 1 0 11 1 0 11 1 0 11 1 0 11 1 0 10 10 10 10 10 10 10 11 1 0 11 1 0 11 1 0 11 11 11 11 11 11 11 11 11 11 10	13P DENNIS	128	1	. 2	0	0 .	131
16S EDWIDGE 61 1 0 0 0 0 6 6 17S FLOSSY 47 0 0 0 0 0 0 4 18S KIRSTY 98 0 11 1 0 11 1 0 11 1 1 0 11 1 1 1 0 11 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	14S DOLORESSE	44	3	0	0 .	0	47
17S FLOSSY 47 0 0 0 0 0 4 18S KIRSTY 98 0 11 1 0 11 19P ETHEL 93 1 9 1 0 10 20P ZAKA 13 0 0 0 0 0 0 21P ATU 57 1 1 2 2 0 6 22S GUYLIANNE 47 2 0 0 0 0 0 4 23P BETI 144 4 0 9 0 0 15 24S HANSELLA 56 4 0 0 0 0 6 25S OLIVIA 138 2 0 0 0 0 14 26S ITELLE 118 3 0 0 0 0 12 27S 110 0 0 0 0 0 12 28S JENNA 121 0 0 0 0 0 12	158	28	- 1	2	0	0	31
18S KIRSTY 98 0 11 1 0 11 19P ETHEL 93 1 9 1 0 10 20P ZAKA 13 0 0 0 0 0 1 21P ATU 57 1 1 2 0 6 6 22S GUYLIANNE 47 2 0 0 0 0 4 23P BETI 144 4 0 9 0 15 24S HANSELLA 56 4 0 0 0 6 25S OLIVIA 138 2 0 0 0 0 26S ITELLE 118 3 0 0 0 0 12 27S 110 0 0 0 0 0 12 28S JENNA 121 0 0 0 0 0 0 12	16S EDWIDGE	61	i	. 0	0	0	62
19P ETHEL 93 1 9 1 0 10 20P ZAKA 13 0 0 0 0 0 1 21P ATU 57 1 1 2 0 6 6 22S GUYLIANNE 47 2 0 0 0 0 4 23P BETI 144 4 0 9 0 15 24S HANSELLA 56 4 0 0 0 6 25S OLIVIA 138 2 0 0 0 14 26S ITELLE 118 3 0 0 0 12 27S 110 0 0 0 0 0 12 28S JENNA 121 0 0 0 0 0 12	17S FLOSSY	47	0	0	0	0	47
20P ZAKA 13 0 0 0 0 0 1 21P ATU 57 1 1 2 0 6 22S GUYLIANNE 47 2 0 0 0 4 23P BETI 144 4 0 9 0 15 24S HANSELLA 56 4 0 0 0 6 25S OLIVIA 138 2 0 0 0 14 26S ITELLE 118 3 0 0 0 12 27S 110 0 0 0 0 12 28S JENNA 121 0 0 0 0 0 12	18S KIRSTY	98	0	11	1	0	110
21P ATU 57 1 1 2 0 6 22S GUYLIANNE 47 2 0 0 0 4 23P BETI 144 4 0 9 0 15 24S HANSELLA 56 4 0 0 0 6 25S OLIVIA 138 2 0 0 0 14 26S ITELLE 118 3 0 0 0 0 12 27S 110 0 0 0 0 0 12 28S JENNA 121 0 0 0 0 0 12	19P ETHEL	93	1	9	1	0	104
22S GUYLIANNE 47 2 0 0 0 4 23P BETI 144 4 0 9 0 15 24S HANSELLA 56 4 0 0 0 6 25S OLIVIA 138 2 0 0 0 14 26S ITELLE 118 3 0 0 0 0 12 27S 110 0 0 0 0 0 12 28S JENNA 121 0 0 0 0 0 12	20P ZAKA	13	0	0	0	Ō	13
23P BETI 144 4 0 9 0 15 24S HANSELLA 56 4 0 0 0 0 25S OLIVIA 138 2 0 0 0 0 26S ITELLE 118 3 0 0 0 0 27S 110 0 0 0 0 0 28S JENNA 121 0 0 0 0 0 12	21P ATU	57	1	1	2	0 -	61
24S HANSELLA 56 4 0 0 0 6 25S OLIVIA 138 2 0 0 0 14 26S ITELLE 118 3 0 0 0 0 12 27S 110 0 0 0 0 0 11 28S JENNA 121 0 0 0 0 0 12	22S GUYLIANNE	47	2	0	0	0	49
25S OLIVIA 138 2 0 0 0 14 26S ITELLE 118 3 0 0 0 12 27S 110 0 0 0 0 0 11 28S JENNA 121 0 0 0 0 12	23P BETI	144	4	0	9	0	157
26S ITELLE 118 3 0 0 0 12 27S 110 0 0 0 0 0 11 28S JENNA 121 0 0 0 0 0 12	24S HANSELLA	56	. 4	0	0	0	60
27S 110 0 0 0 0 11 28S JENNA 121 0 0 0 0 12	25S OLIVIA	138	2	0	0	0	140
27S 110 0 0 0 0 0 11 28S JENNA 121 0 0 0 0 12	26S ITELLE	118	3	0	0	0	121
	27S	110	. 0	0	0	0	110
Tabelo 250 21 50 24 0 250	28S JENNA	121	0	0	0	0	121
Totals 2,559 51 50 24 0 2,04	Totals	2,539	31	50	24	0	2,644

3. SUMMARY OF WESTERN NORTH PACIFIC AND NORTH INDIAN OCEAN TROPICAL CYCLONES

3.1 WESTERN NORTH PACIFIC OCEAN TROPICAL CYCLONES

The year of 1996 was busy for the Joint Typhoon Warning Center (JTWC), with a near record number of significant tropical cyclones (TCs) occurring in the western North Pacific (WNP) (Table 3-1); 43 versus 44 which was the record set in 1964 (Table 3-2).

This number was almost 40% higher than the climatological average of 31 significant TCs in the WNP for the 37-year period 1959-1995. The year of 1996 included six super typhoons, 15 lesser typhoons, 12 tropical storms and 10 tropical depressions. The calendar-year total of 33 TCs of at least tropical-storm intensity was 5 above the long-term average (Figure 3-1). The calendar-year total of 21 typhoons

			NUMBER OF		IMATED XIMUM	t
			WARNINGS		CE WINDS	ESTIMATE
TDADT	CAL CYCLONE	PERIOD OF WARNING	ISSUED	KT	(M/SEC)	MSLP (MB)
01W	TD	29 FEB - 01 MAR	7	30	(15)	1000
02W	TS ANN	02 APR - 09 APR	27	40	(21)	994
03W	TD	25 APR - 26 APR	4	25	(13)	1002
04W	TY BART	09 MAY - 18 MAY	39	125	(64)	916
05W	TS CAM	18 MAY - 24 MAY	22	60	(31)	980
06W	TY DAN	05 JUL - 12 JUL	30	75	(39)	967
07W	STY EVE	13 JUL - 20 JUL	27	140	(72)	898
08W	TY FRANKIE	21 JUL - 24 JUL	14	90	(46)	954
09W	TY GLORIA	22 JUL - 27 JUL	22	90	(46)	954
10W	STY HERB	23 JUL - 01 AUG	38	140	(72)	898
11W	TS IAN	28 JUL - 31 JUL	10	40	(21)	994
12W	TY JOY	29 JUL - 05 AUG	28	75	(39)	967
13W	TY KIRK	03 AUG - 16 AUG	51	95	(49)	949
14W	TS LISA	05 AUG - 07 AUG	8	40	(21)	994
15W	TD	12 AUG - 16 AUG	9	30	(15)	1000
16W	TS MARTY	13 AUG - 14 AUG	3	50	(26)	987
17W	TD	14 AUG	2	30	(15)	1000
18W	TY NIKI	18 AUG - 23 AUG	21	95	(49)	949
19W	TY ORSON	21 AUG - 03 SEP	51	115	(69)	927
20W	TY PIPER	23 AUG - 26 AUG	14	65	(33)	976
21W	TD	26 AUG - 27 AUG	4	25	(13)	1002
22W	TS RICK	28 AUG - 31 AUG	10	35	(18)	997
23W	STY SALLY	05 SEP - 09 SEP	19	140	(72)	898
24W	TS	09 SEP - 14 SEP	16	45	(23)	991
25W	TY TOM	11 SEP - 20 SEP	35	75	(39)	957
26W	STY VIOLET	11 SEP - 23 SEP	44	130	(67)	910
27W	TY WILLIE	17 SEP - 23 SEP	22	65	(33)	976
28W	STY YATES	22 SEP - 01 OCT	37	130	(67)	910
29W	TY ZANE	24 SEP - 03 OCT	39	110	(57)	933
30W	TS ABEL	11 OCT - 17 OCT	21	50	(26)	987
31W	TD	13 OCT - 17 OCT	13	25	(13)	1002
32W 33W	TY BETH TY CARLO	13 OCT - 21 OCT	33	90	(46)	954
33W 34W	TY CARLO	21 OCT - 26 OCT 29 OCT - 30 OCT	24	105 30	(54)	938
34W 35W	TD TS	02 NOV - 03 NOV	4 6	30 40	(15)	1000 994
36W	STY DALE	04 NOV - 03 NOV	ь 39	140	(21)	994 898
30W 37W	TS ERNIE	04 NOV - 13 NOV	39 48	50	(72)	987
37W 38W	TS ERNIE	06 NOV - 08 NOV	48 5	50 50	(26) (26)	987 992
39W	TD	08 NOV - 08 NOV	3	30	(26)	1000
39W 40W	TD	25-27 NOV/29-01 DEC	15	25	(13)	1000
41W	TD	14 DEC - 20 DEC	13	30	(15)	1002
42W	TY FERN	21 DEC - 30 DEC	35	. 80	(41)	963
43W	TS GREG	24 DEC - 27 DEC	10	45	(23)	991

was 3 above the long term average. Six of the typhoons became super typhoons, two over the climatological average (Figure 3-2).

Thirty-one of the 43 significant TCs in the WNP during 1996 originated in the low-latitude monsoon trough or near-equatorial trough. Eleven — Dan (06W), Eve (07W), Joy (12W), Tropical Depression (TD) 15W, TD 17W, Piper (20W), TD 21W, Rick (22W), TD 23W, Carlo (33W), and Tropical Storm

38W — formed at relatively high latitude in association with cold-core cyclonic vortices (cells) in the tropical upper-tropospheric trough (TUTT). There were no significant TCs in the WNP during 1996 which originated east of the international date line. Historically, about one TC per year numbered/named by the Central Pacific Hurricane Center or the National Hurricane Center moves into the WNP.

Table	3-2	DIS	TRIBU	TION O	F WEST	ERN NO	ORTH PA	ACIFIC	TROPI	CAL CY	CLONE	S FOR 1	1959 - 1996
YEAR	JAN	FEB	MAR	APR	MAY	JUN	<u> î</u>	AUG	SEP	OCT	МОЛ	DEC	TOTALS
1959	000	1 010	1 010	1 100	0 000	1 001	3 111	8	9 423	3	2	2 200	31 17 7 7
1960	1	010	1	100	1	3	3	512 9	423	210 4	200 1	200	17 7 7 30
1300	001	000	001	100	010	210	210	810	041	400	100	100	19 8 3
1961	1	1	1	1	4	6	5	7	6	7	2	1	42
	010	010	100	010	211	114	320	313	510	322	101	100	20 11 11
1962	0	1	0	1	3	0	8	8	7	5	4	2	39
	000	010	000	100	201	000	512	701	313	311	301	020	24 6 9
1963	0	0	1	1	0	4	5	4	4	6	0	3	28
	000	000	001	100	000	310	311	301	220	510	000	210	19 6 3
1964	0	0	0	0	3	2	8	8	8	7	6	2	44
	000	000	000	000	201	200	611	350	521	331	420	101	26 13 5
1965	2	2	1	1	2	4	6	7	. 9	3	2	1	40
	110	020	010	100	101	310	411	322	531	201	110	010	21 13 6
1966	0	0	0	1	2	1	4	9	10.	4	5	2	38
1067	000 1	000 0	000 2	100	200 1	100	310	531	532	112	122	101	20 10 8
1967	010	000	110	1 100	010	1 100	8 332	10 343	8 530	4 211	4 400	1 010	41 20 15 6
1968	0	1	0	1	0	4	3	8	4	6	4	0	31
1,500	000	001	000	100	000	202	120	341	400	510	400	000	20 7 4
1969	1	0	1	1	0	0	3	3	6	5	2	1	23
	100	000	010	100	000	000	210	210	204	410	110	010	13 6 4
1970	0	1	0	0	0	2	3	7	4	6	4	0	27
	000	100	000	000	000	110	021	421	220	321	130	000	12 12 3
1971	1	. 0	1	2	5	2	8	5	7	4	2	0	37
	010	000	010	200	230	200	620	311	511	310	110	000	24 11 2
1972	1	0	1	0	0	4	5	5	6	5	. 2	3	32
	100	000	001	000	000	220	410	320	411	410	200	210	22 8 2
1973	0	0	0	0	0	0	7	6	3	4	3	0	23
	000	000	000	000	000	000	430	231	201	400	030	000	12 9 2
1974	1 010	000	1 010	1 010	1 100	4 121	5 230	7 232	5 320	4 400	4 220	2 020	35
1975	1	0	010	1	0	0	230	232 6	320 5	400	3	2	15 17 3 25
13/3	100	000	000	001	000	000	010	411	410	321	210	002	14 6 5
1976	1	1	0	2	2	2	4	4	5	0	2	2	25
	100	010	000	110	200	200	220	130	410	000	110	020	14 11 0
1977	0	0	1	0	1	1	4	2	5	4	2	1	21
	000	000	010	000	001	010	301	020	230	310	200	100	11 8 2
1978	1	0	0	1	0.	3	4	8	4	7	4	0	32
	010	000	000	100	000	030	310	341	310	412	121	000	15 13 4
1979	1	0	1	1	2	0	5	4	6	3	2	3	28
	100	000	100	100	011	000	221	202	330	210	110	111	14 9 5
1980	0	0	1	1	4	1	5	3	7	4	1	,1	28
	000	000	001	010	220	010	311	201	511	220	100	010	15 9 4
1981	0	0	1	1	1	2	5	8	4	2	3	2	29
1000	000	000	100	010	010	200	230	251	400	110	210	200	16 12 1
1982	0	. 0	3	0	1	3	4	5	6	4	1	1	28
1983	000	000	210 0	000	100 0	120 1	220 3	500 6	321 3	301 5	100 5	100	19 7 2 25
1303	000	000	000	000	000	010	300	231	111	320	320	2 020	12 11 2
	000	000	550								320	020	12 11 2
l '				TABLE	CONT	INUED	ON TO	OP OF	NEXT	PAGE			
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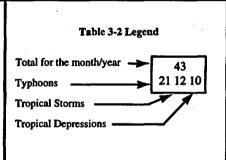
Table	3-2	(CON	CINUED	FROM	PREV	IOUS	PAGE)						
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOY	DEC	TOTALS
1984	0	0	. 0	0	0	2	5	7	4 .	8	3	1	30
	000	000	000	000	000	020	410	232	130	521	300	100	16 11 3
1985	2	0	0	Ð	1	3	1	7	5	5	-1	2	27
*	020	000	000	000	100	201	100	520	320	410	010	110	17 9 1
1986	0	1	0	1	2	2	2	5	2	5	4	` 3	27
	000	100	000	100	110	110	200	410	200	320	220	210	19 8 0
1987	1	0	0	1	0	2	4	4	7	2	3	1	25
	100	000	000	010	000	110	400	310	511	200	120	100	18 6 1
1988	1	0	. 0	0	1	3	2	5	- 8	4	- 2	1	27
	100	000	000	000	100	111	110	230	260	400	200	010	14 12 1
1989	1	0	0	1	2	2	6	- 8	4	6	3	2	35
	010	000	000	100	200	110	231	332	220	600	300	101	21 10 4
1990	1	0	0 1	1	2	4	4	5	5	5	4	1	31
	100	000	000	010	110	211	220	500	410	230	310	100	21 9 1
1991	0	0	2	1	1	1	4	8	6	3	6	0	32
	000	000	110	010	100	100	400	332	420	300	330	000	20 10 2
1992	1	1	0 .	0	0	3	4	8	5	6	5	0	33
	100	010	000	000	000	210	220	440	410	510	311	000	21 11 1
1993	0	0	2	2	1	2	5	. 8	5	6	4	3	38
	000	000	011	002	010	101	320	611	410	321	112	300	21 9 8
1994	1	0	1	0	2	2	9	9	8	7	0	2	41
	001	000	100	000	101	020	342	630	440	511	000	110	21 15 5
1995	1	0	0	0	1	2	3	7	7	8	2	3	34
	001	000	000	000	010	020	210	421	412	512	020	012	15 11 B
1996	0	1	0	2	2	0	7	10	7	5	6	3	43
	000	001	000	011	110	000	610	433	610	212	132	111	21 12 10
(1959-19	95)												
MEAN	0.6	0.3	0.6	0.8	1.3	2.2	4.7	6.6	5.9	4.9	3.0	1.5	31.4
CASES	22	10	23	27	46	79	168	238	212	177	107	54	1163

The criteria used in Table 3-2 are as follows:

1) If a tropical cyclone was first warned on during the last two days of a particular month and continued into the next month for longer than two days, then that system was attributed to the second month.

If a tropical cyclone was warned on prior to the last two days of a month, it was attributed to the first month, regardless of how long the system lasted.

3) If a tropical cyclone began on the last day of the month and ended on the first day of the next month, that system was attributed to the first month. However, if a tropical cyclone began on the last day of the month and continued into the next month for only two days, then it was attributed to the second month.



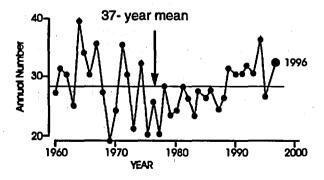


Figure 3-1 Tropical cyclones of tropical storm or greater intensity in the western North Pacific (1960-1996)

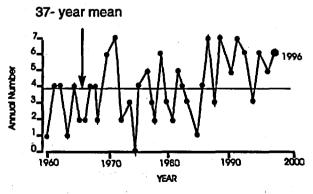


Figure 3-2 Number of western North Pacific super typhoons (1960-1996).

The 1996 year was a continuation of a weak cold phase of the El Niño/Southern Oscillation (ENSO) which began during 1995. Large-scale atmospheric and oceanic circulation anomalies during 1996 were generally as expected for a weak cold phase of ENSO (sometimes referred to as La Niña, or El Viejo). For example, the sea-surface temperature (SST) along the equator in the central and eastern Pacific was colder than normal (Figure 3-3), the Southern Oscillation Index (SOI) was positive (Figure 3-3), and low-level easterly wind anomalies persisted in the low latitudes of the WNP (Figure 3-4).

The annual mean genesis location of TCs which form in the WNP is related to the status of ENSO: it tends to be east of normal during El Niño years and west of normal during El Viejo years. Consistent with the TC distribution associated with a cold phase of ENSO, the annual mean genesis location during 1996 was west of normal (Figure 3-5a), as it was during 1995. It was also slightly north of normal. A breakdown of the genesis locations of all 1996 WNP TCs (Figure 3-5b) shows that most formed between 120°E and 160°E. Only five formed east of 160°E, while ten — six more than normal — formed in the

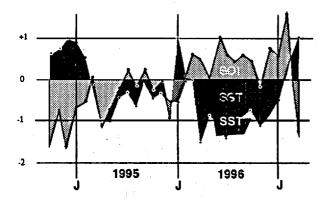


Figure 3-3 Anomalies from the monthly mean for eastern equatorial Pacific Ocean sea-surface temperature (hatched) in degrees Celsius and the Southern Oscillation Index (SOI) (shaded) for the period 1995 through 1996. (Adapted from Climate Prediction Center, 1996).

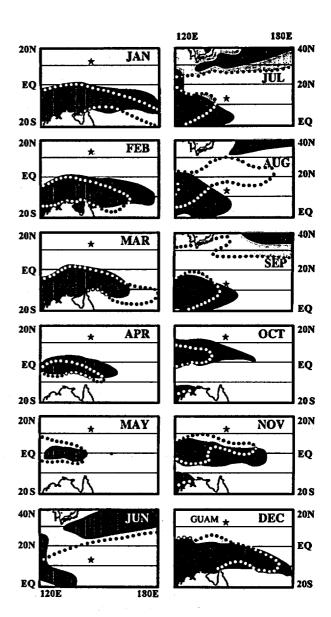


Figure 3-4 Comparison between climatological (black) and analyzed (shaded) mean monthly winds with a westerly component for the WNP in 1996. For June, July and August the area of coverage is shifted northward to include the subtropics. For reference, the star indicates the location of Guam. The outline of Australia appears in the lower left of each panel except for June, July and August and September where the Korean peninsula and Japan appear in the upper left. The climatology is adapted from Sadler, et al. (1987). The 1996 monthly mean winds were adapted from the Climate Prediction Center (1996).

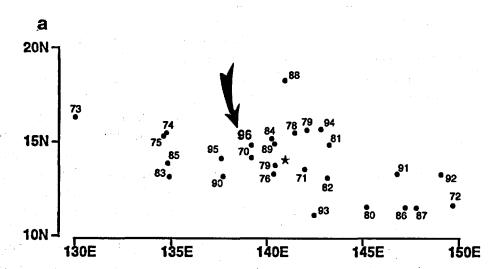


Figure 3-5a Mean annual genesis locations for the period 1970-1996. 1996's location is indicated by the arrow. The star lies at the intersection of the 27-year average latitude and longitude of genesis. For statistical purposes, genesis is defined as the first 25-kt (13-m/sec) intensity on the best track.

South China Sea, contributing to the westward displacement of the annual mean genesis location. Only one TC formed east of 160°E and south of 20°N in a region designated on Figure 3-5b as the "El Niño" box. The annual number of TCs which form in the "El Niño" box is much greater during El Niño years than during El Viejo years (Lander, 1994). During El Viejo years the few TCs which form east of 160°E tend to occur north of 20°N and are often associated with TUTT cells.

During June through October of 1996, low-level easterly wind flow was unusually persistent in the low latitudes of the WNP (Figure 3-4), and the normal southwest monsoon of the Philippine Sea (with its episodic extensions further eastward) was replaced by mean monthly easterly flow. Corresponding anomalies in the upper troposphere consisted of westerly wind anomalies over the low latitudes of the WNP. Similar large-scale wind anomalies dominated the low latitudes of the WNP during 1995, and may have been related

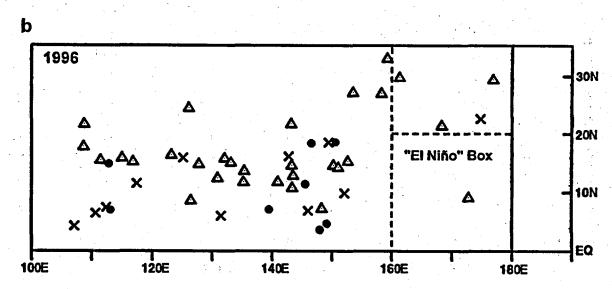


Figure 3-5b Point of formation of significant tropical cyclones in 1996 as indicated by the initial intensity of 25 kt (13 m/sec) on the best track. The symbols indicate: solid dots = 01 January to 15 July; open triangles = 16 July to 15 October; and, X = 16 October to 31 December.

to a westward displacement of the mean genesis location during that year. Despite similar wind anomalies in low latitudes, there were far more TCs during 1996 than during 1995. Some factors suggested for the enhanced number of TCs during 1996 include:

- 1) a high number of TUTT-cell related TCs during 1996;
- 2) an unusual eastward penetration of the monsoon trough at high latitudes during August of 1996 (Figure 3-6); and,
- 3) a return of near-normal monsoonal westerlies during November and December.

The most distinctive characteristic of the WNP TC distribution during 1996 was the large number of TUTT-cell related TCs. Eleven (26%) of the 43 significant TCs in the WNP during 1996 formed in association with TUTT cells. TUTT-cell related TC genesis is described in detail in Joy's (12W) summary.

Another distinctive characteristic of the TC distribution during 1996 was the formation of several TCs at high latitude in association with a displacement of the monsoon trough during August well to the north of normal. A northward-displaced monsoon trough was the site of the development of Kirk (13W), Orson (19W), Piper (20W), and Rick (22W), and TDs 15W, 17W, and 23W. Some of these TCs (e.g., Piper (20W) and Rick (22W)) also formed in association with TUTT cells.

During November and December of 1996, monsoonal westerlies returned to a near-normal distribution. Two episodes of strong low-level equatorial westerly winds (sometimes referred to as equatorial westerly wind bursts) occurred, one during early November and the other during the latter half of December. The November westerly wind burst was associated with the development of the late-season TCs

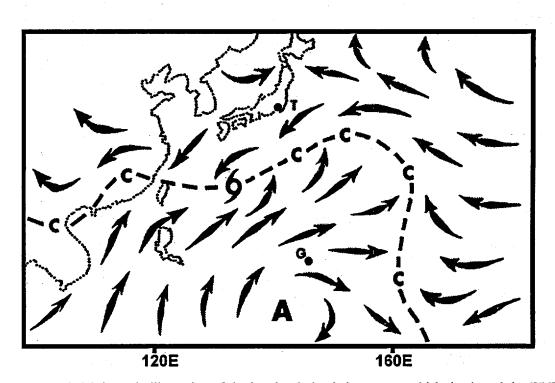


Figure 3-6 Schematic illustration of the low-level circulation pattern which dominated the WNP during August. Arrow indicates wind direction, dashed line indicates the axis of the monsoon trough, C indicates LLCCs, A = anticyclone center, G = Guam, and T = Tokyo. A TC is shown located along the trough axis.

Dale (36W) and Ernie (37W). December's episode of strong equatorial westerly wind was associated with the development of five TCs — two in the Northern Hemisphere (Fern (42W) and Greg (43W)), and three in the Southern Hemisphere (Ophelia (11S), Phil (12P), and Fergus (13P)).

The tracks of the TCs which formed in the WNP during 1996 indicate an above-normal number of TCs (10) in the South China Sea (SCS), and an above-normal number (12) of north-oriented tracks (which includes the three "S" tracks as a specific type of north-oriented motion). Of the 43 TCs, nine (21%) were straight runners, eight (19%) were recurvers, twelve (28%) moved on north-oriented tracks, and fourteen (32%) were designated as "other". Of the twelve TCs which

moved on north-oriented tracks during 1995, three underwent "S" motion. Ten of the fourteen "other" TCs remained in or near the SCS. The three "S" tracks occurred in association with a northward-displaced monsoon trough during August.

In summary, a chronology of all the TC activity in the JTWC AOR during 1996 is provided in Figure 3-7. Composite best tracks for the WNP TCs are provided for the periods: 01 January to 08 August (Figure 3-8a), 09 August to 07 October (Figure 3-8b), and 08 October to 31 December (Figure 3-8c). Table 3-3 includes: a climatology of typhoons, and tropical storms/typhoon for the WNP for the periods 1945-1959 and 1960-1996. Table 3-4 is a summary of the TCFA's for the WNP for the period 1976-1996.

TYPHOONS	(1945-	<u> 1959)</u>											
	<u>JAN</u>	<u>FEB</u>	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
MEAN	0.3	0.1	0.3	0.4	0.7	1	2.9	3.1	3.3	2.4	2	0.9	16.
CASES	5	1	4	6	10	15	29	46	49	36	30	14	24
TYPHOONS	(1960-	1996)											
	JAN	<u>FEB</u>	MAR	APR	MAY	<u>JUN</u>	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
MEAN	0.3	0.1	0.2	0.4	0.7	1	2.8	3.4	3.4	3.2	1.7	0.7	17.
CASES	10	2	8	15	26	38	104	126	126	120	62	25	66
TROPICAL	STORMS	AND T	PHOONS	(1945	-1996)								
	<u>JAN</u>	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
MEAN	0.4	0.1	0.5	0.5	0.8	1.6	2.9	4	4.2	3.3	2.7	1.2	22.
CASES	6	2	7	8	11	22	44 .	60	64	49	41	18	332
TROPICAL	STORMS	AND T	PHOONS	(1960	-1996)								
	JAN	<u>FEB</u>	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV-	DEC	TOTAL
MEAN	0.5	0.2	0.5	0.6	1.1	1.8	4.3	5.6	5.1	4.3	2.7	1.2	28
CASES	19	9	17	23	41	67	159	208	189	159	100	46	103

Table 3-4 TROPICAL CYCLONE FORMATION ALERTS FOR THE WESTERN NORTH PACIFIC OCEAN FOR 1976-1996

		TROPICAL	TOTAL	PROBABILITY OF	PROBABILITY OF
	INITIAL	CYCLONES	TROPICAL	TCFA WITHOUT	TCFA BEFORE
YEAR	TCFAS	WITH TCFAS	CYCLONES	WARNING*	WARNING
1976	34	25	25	26%	100%
1977	26	20	21	23%	95%
1978	32	27	32	16%	84%
1979	27	23	28	15%	82%
1980	37	28	28	24%	100%
1981	29	28	29	3%	96%
1982	36	26	28	28%	93%
1983	31	25	25	19%	100%
1984	37	30	30	19%	100%
1985	39	26	27	33%	96%
1986	38	27	27	29%	100%
1987	31	24	25	23%	96%
1988	33	26	27	21%	96%
1989	51	32	35	37%	91%
1990	33	30 .	31	9%	97%
1991	37	29	31	22%	94%
1992	36	32	32	20%	100%
1993	50	35	38	30%	92%
1994	50	40	40	20%	100%
1995	54	33	35	39%	94%
1996	41	39	43	5%	91%
(1976-1996)					
MEAN:	37	29	30	22%	97%
TOTALS:	782	605	637		

^{*} Percentage of initial TCFA's not followed by warnings.

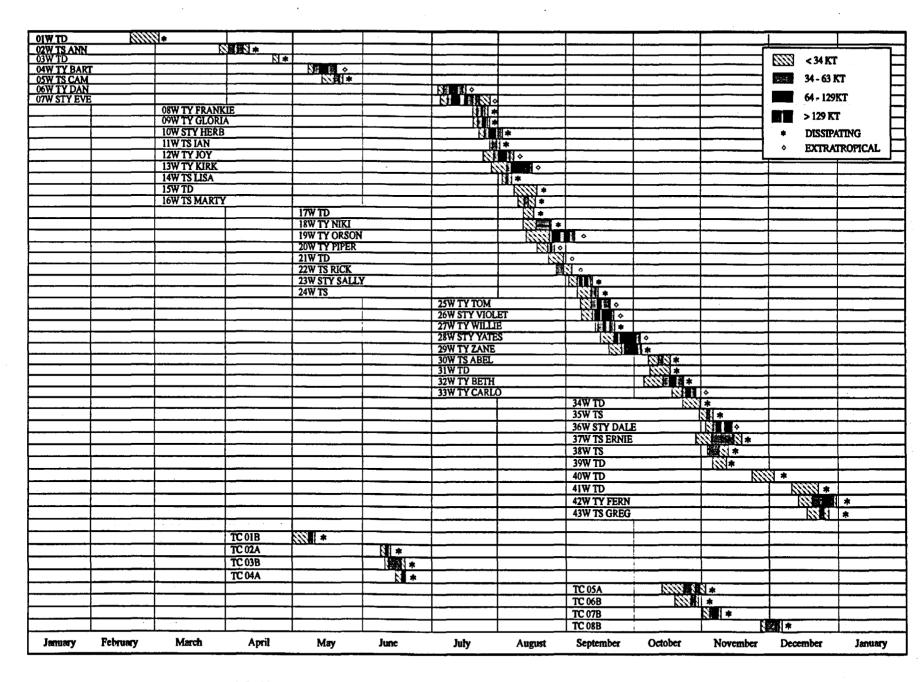


Figure 3-7 Chronology of western North Pacific and North Indian Ocean tropical cyclones for 1996.

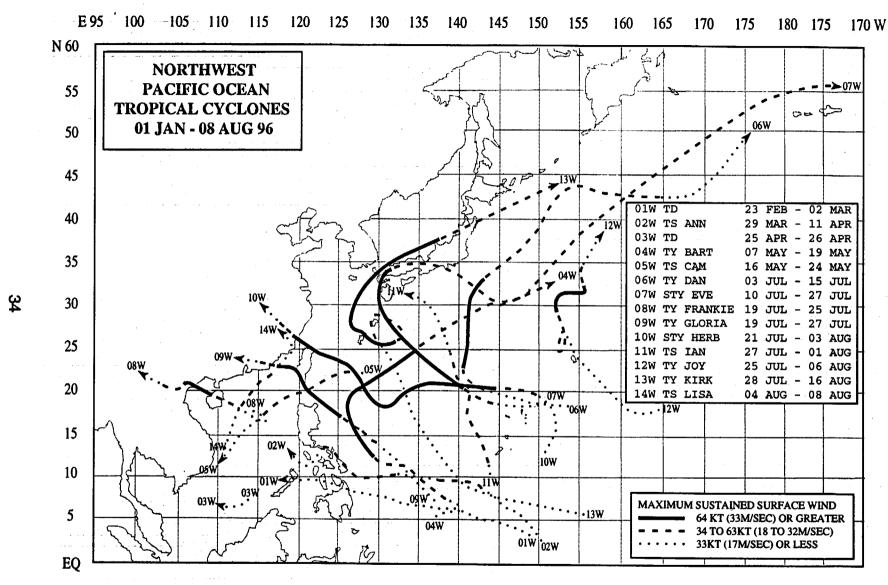


Figure 3-8a Composite best tracks for the western North Pacific Ocean tropical cyclones for the period 01 January to 08 August 1996



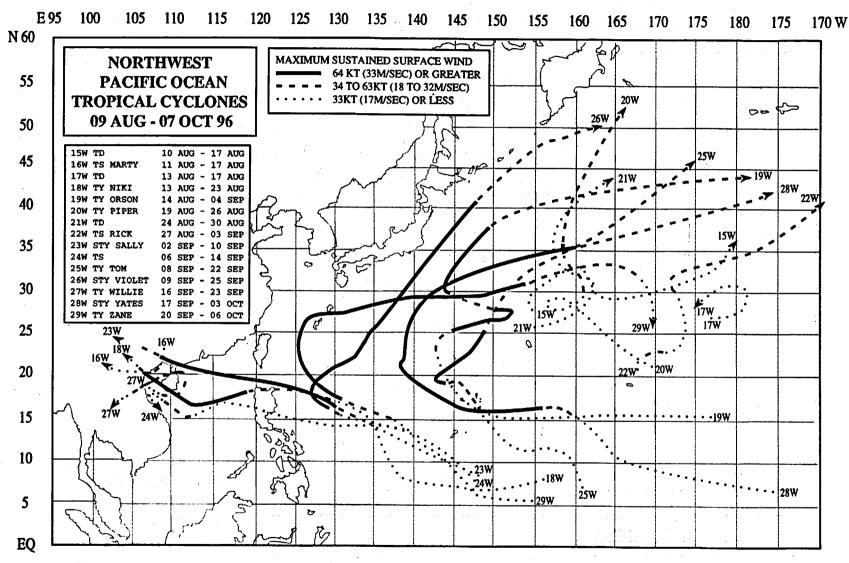


Figure 3-8b Composite best tracks for the western North Pacific Ocean tropical cyclones for the period 09 August to 07 October 1996

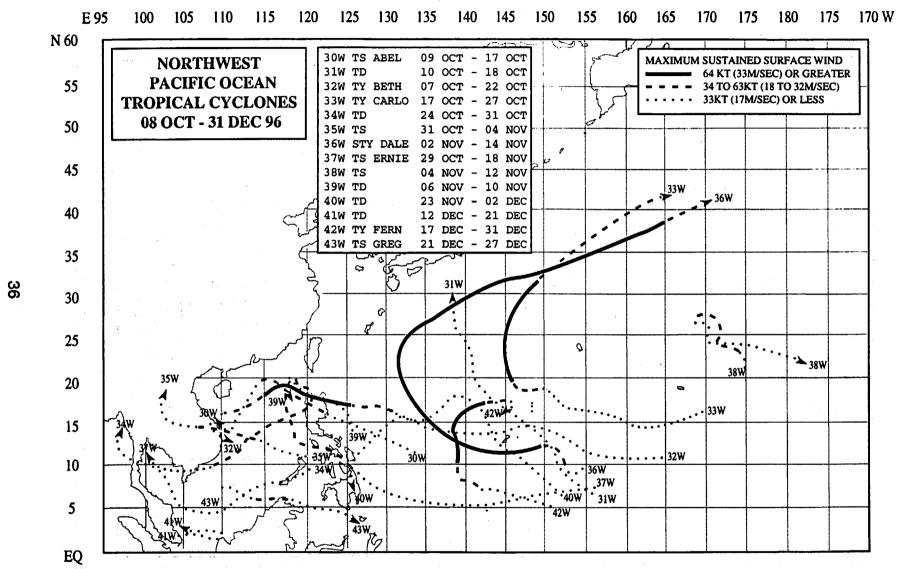


Figure 3-8c Composite best tracks for the western North Pacific Ocean tropical cyclones for the period 08 October to 31 December 1996

3.1.1 MONTHLY ACTIVITY SUMMARY

JANUARY

There were no significant TCs in the western North Pacific basin during January 1996.

FEBRUARY

For only the fourth time since 1970, a significant TC formed in the WNP during February. Toward the end of the month, Tropical Depression (TD) 01W formed south of Guam. It developed in a temporary near-equatorial trough over the Caroline Islands, associated with a short-lived westerly wind burst. Tropical Depression 01W moved to the west-northwest, failed to mature, and on the last day of the month it moved into the Philippine archipelago just north of Mindanao.

MARCH

During the first two days of March, TD 01W completed its passage over the Philippines, entered the SCS and dissipated. For most of the rest of March, the WNP was relatively clear, while several TCs originated within the western South Pacific (WSP). At the end of March, the WSP became quiet, and a broad, persistent area of deep convection extended westward from Hawaii to central Micronesia. On the last two days of March, the tropical disturbance which became Ann (02W) originated at low latitudes southeast of Guam.

APRIL

Two TCs — Tropical Storm (TS) Ann (02W) and TD 03W — were active during April. During the first week of April, Ann became the first named TC of 1996. After becoming a tropical storm while south of Guam, Ann moved westward along 10°N and made landfall in the central Philippines. On 11 April, Ann dissipated over the eastern SCS. The remainder of April was quiet until the last week when an area of persistent deep convection northwest of Borneo became Tropical Depression 03W. TD 03W had a very short life (30 hours).

MAY

During the first week of May, the tropics of the WNP were dominated by low-level easterly wind flow accompanied by westerly wind flow aloft. A zonally-oriented band of convection stretched east-west across Micronesia south of 10°N. By the end of the first week, an area of deep convection began to organize in the western Caroline Islands as monsoonal low-level westerly winds penetrated into the WNP eastward to 140°E and south of 5°N. This area of deep convection became Typhoon Bart (04W), the first typhoon of 1996. Initially moving toward the Philippines, it turned to the north and remained at sea. Undergoing a period of rapid intensification, Bart became a very intense typhoon, peaking at 125 kt (64 m/sec) on 14 May. A day later, the intense typhoon recurved to the northeast, and on 19 May it became extratropical near 30°N 152°E.

As Bart was recurving, cloudiness began to increase in the southwesterly monsoon flow across the SCS and extended east-northeastward toward Bart. Most of the deep convection associated with this monsoon flow was located within the SCS in the form of a large ensemble of mesoscale convective systems (MCSs) which were associated with a weak low-level cyclonic circulation, and extensive cirrus outflow indicative of anticyclonic outflow aloft. These structural attributes are typical of a monsoon depression. The deep convection of this monsoon depression consolidated, and the system became TS Cam (05W). Cam moved toward the east-northeast for its entire life. While at peak intensity, it passed through the Luzon Strait and then slowly weakened as it drifted eastward into the Philippine Sea and dissipated.

JUNE

There were no significant TCs in the WNP during June as amounts of deep convection were below normal, low-level winds were anomalously easterly and upper-level winds were anomalously westerly (Climate Prediction Center (CPC), 1996). While several tropical disturbances developed during the month, a

combination of stronger-than-normal low-level easterly flow with stronger-than normal upper-level westerly flow created an environment of strong vertical shear which was unfavorable for TC formation and development. Since 1959, only five other years have had no significant TCs during June.

JULY

July was a busy month in the WNP with a total of eight TCs. Early in the month, the southwest monsoon remained inactive in the WNP with large-scale wind anomalies similar to those of June. The first two TCs of the month, Typhoon Dan (06W) and Super Typhoon Eve (07W), formed in association with TUTT cells. Typical of TC genesis in association with TUTT cells, Dan and Eve formed at relatively high latitude (Dan at 24°N, and Eve at 20°N), and both formed in low-level easterly flow. On 15 July, Eve underwent a period of explosive intensification and reached a peak of 140 kt (72 m/sec), becoming the first super typhoon in the WNP during 1996. The first TC of the year to make landfall as a typhoon, Eve passed through the northern Ryukyu Islands and made landfall in southern Japan.

In the middle of July, the monsoon began to move eastward as the axis of the monsoon trough extended into Micronesia. Extensive amounts of deep convection formed in an east-west band extending across the WNP from the coast of Southeast Asia to the Marshall Islands. By 21 July, this cloud band had consolidated into three distinct cloud clusters, all of which became named TCs — from west to east: Typhoon Frankie (08W), Typhoon Gloria (09W), and Super Typhoon Herb (10W). Frankie originated from a monsoon depression in the SCS. It became a typhoon in the Gulf of Tonkin and went ashore in Vietnam late on 23 July. While Frankie was developing in the SCS, a monsoon depression in the Philippine Sea became Gloria. Gloria moved northwestward, became a typhoon, and affected Luzon, Taiwan, and eastern China. During the early phases of its development,

Gloria formed a very large Central Cold Cover (CCC) with a near-record cloud-top temperature of -100°C. As Frankie and Gloria moved westward. Herb formed and became the easternmost of three tropical cyclones simultaneously active along the monsoon trough. Herb became a super typhoon when east of Taiwan. A very intense TC, it was also very large — the largest TC in terms of the mean radius to its outermost closed isobar in the WNP during 1996. Herb made landfall in the southern Ryukyu Islands, Taiwan, and mainland China. Significant property damage and loss of life were attributed to Herb in these areas. On Taiwan, a brand new NEXRAD WSR-88D took a direct hit from Herb, and was severely damaged. As Herb moved westward toward Taiwan, TS Ian (11W) formed near Guam at the end of the monsoon trough and then moved on a north-northwestward track while embedded within the peripheral southerly flow on the eastern side of the very large Super Typhoon Herb (10W). Ian appeared to be adversely affected by Herb's upper-level outflow, and did not intensify above 40 kt (21 m/sec).

At the end of July, as Herb moved westward, a TUTT cell generated a tropical disturbance in the eastern part of the WNP basin near 20°N 165°E. This tropical disturbance became Typhoon Joy (12W). Joy did not become a typhoon until 01 August when it had moved to nearly 30°N. Also by the end of July, a new monsoon trough began to form at low latitudes in Micronesia, replacing the monsoon trough which moved with Herb into China. The monsoon depression which became Typhoon Kirk (13W) formed south of Guam in late July, but did not become a named TC until the first week of August.

AUGUST

August was also a very busy month, with eight TCs developing during the month, and four of the July TCs — Ian (11W), Herb (10W), Joy (12W), and Kirk (12W) — carrying over into the early part of the month. On 01 August, Ian dissipated south of Japan. Herb dissipated over eastern China on 03 August.

Joy, which developed near 20°N 165°E in the last week of July, reached typhoon intensity on 01 August. It moved on a north-oriented track and merged with a frontal cloud band on 06 August. Typhoon Kirk (13W), the last of the TCs originating during July, developed from a monsoon depression at low latitude, and did not significantly intensify until reaching 27°N on 05 August. The typhoon moved on a complex north-oriented track which saw it undergo an unusual clockwise loop before passing directly over Okinawa where it took a full 12 hours for its 70-nm (130-km) diameter eye to pass. Kirk recurved near Okinawa, intensified to its peak of 95 kt (49 m/sec), moved to the northeast, and made landfall in Kyushu on 14 August.

During the period 04-17 August (as the large slow-moving Kirk tracked northward, executed its clockwise loop, and recurved), four relatively weak TCs formed elsewhere in the WNP. TS Lisa (14W) was the first TC to form during August. It originated from a monsoon depression in the SCS. Moving northeastward, the system attained only 40 kt (21 m/sec); and late on 06 August it made landfall west of Taiwan in east central China. On 12 August, TD 15W developed in the subtropics at a time when the monsoon trough was displaced far to the north of normal. Although it was located along the axis of this northward-displaced monsoon trough, the structure of the very small TD 15W was influenced by a northward-displaced TUTT, and an upper-level cut-off low to the east of Japan. The system dissipated over water on 17 August. TS Marty (16W) originated as a tropical disturbance in the monsoon trough over land in southwestern China. This disturbance moved southward into the Gulf of Tonkin and intensified to a tropical storm on 13 August. The system then turned more to the west and, after a short path over water, it made landfall about 60 nm (110 km) south of Hanoi. Marty was reported to have severely impacted Vietnamese fishing boats in the Gulf of Tonkin where 125 people were reported killed and another 107 missing. TD 17W formed to the east-southeast of TD 15W at the eastern end of the northward-displaced monsoon trough. This TD tracked eastward across the international

date line, then doubled back and crossed the date line again. On 17 August after a short life and a short track, TD 17W dissipated over water near 27°N 177°E.

During the middle of August, as TDs 15W and 17W developed along the axis of a monsoon trough which was displaced to a higher-than-normal latitude, a ridge of high pressure to its south produced easterly low-level winds across the deep tropics of the WNP. Within these low-latitude easterly winds, several tropical disturbances formed. The tropical disturbance which became Typhoon Niki (18W) can be traced to a small ensemble of MCSs which appeared in the eastern Caroline Islands on 13 August. This disturbance moved westward and slowly developed. It became a tropical storm after it crossed 130°E and before it crossed Luzon. Niki did not become a typhoon until it was in the SCS. The typhoon passed over the southern tip of Hainan Island, crossed the Gulf of Tonkin, and made landfall in northern Vietnam. The tropical disturbance which became Typhoon Orson (19W) developed within a very complex circulation pattern that can best be described as the early stages of the breakdown of the high-latitude monsoon trough within which Kirk (13W), TD 15W, and TD 17W were located. When the pre-Orson tropical disturbance formed on 15 August, Kirk (13W) was moving eastward over northern Honshu (and becoming extratropical), and TDs 15W and 17W were dissipating at high latitude (30°N) and east of 160°E. For the next four days, the pre-Orson tropical disturbance tracked westward along 15°N. On 19 August, it turned northward and intensified. Orson had a complex history, including two periods of intensification, the formation of a very large eye, and a highly erratic track.

When Orson became a typhoon while moving east-northeastward at 25°N, the monsoon trough became reestablished at a high latitude. The final three TCs of August developed at high latitude in this monsoon trough, and were also associated with TUTT cells. Typhoon Piper (20W) was another of the TCs of 1996 which originated in association with a TUTT cell. It was a very small TC — easily

the smallest typhoon in the WNP during 1996. Developing at a relatively high latitude to the east of Orson (19W), Piper was located at the eastern end of a high-latitude reverse-oriented monsoon trough. Typical of TCs associated with a reverse-oriented monsoon trough, Piper moved on a north-oriented "S"-shaped track. On 26 August, the typhoon accelerated toward the north-northeast and was absorbed into a frontal cloud band east of the Kamchatka peninsula. On 24 August, the weak low-level circulation which became TD 21W developed east of Orson and west of Piper. Sandwiched between these two TCs, TD 21W remained weak while in an environment of westerly vertical wind shear. After moving on a north-oriented "S"-shaped track, the system dissipated over water near 42°N 163°E early on 30 August. TS Rick (22W) formed after Piper and TD 21W moved out of the high-latitude monsoon trough on their north-oriented "S"-shaped tracks. The tropical disturbance which became Rick was located between Orson (19W) and a welldefined TUTT cell. In addition to its association with a TUTT cell, Rick also became part of the monsoon trough. Located at the eastern end of the high-latitude monsoon trough, it moved on a north-oriented "S"-shaped track. On 31 August, the system entered the accelerating westerlies regime north of the subtropical ridge, and by 03 September it dissipated north of 40°N and east of the international date line.

SEPTEMBER

TC activity in the WNP during September continued at a fast pace, with no break from the high levels of TC activity of July and August. The month produced seven TCs, including six typhoons (half of which became super typhoons). As the month began, two TCs — Rick and Orson — were still active from August. Rick dissipated on 03 September, and Orson became extratropical on 04 September.

As the long-lived Orson recurved at the beginning of September, the unusual monsoon flow pattern of August gave way to a pattern more in line with climatology: the maximum cloud zone and the axis of the monsoon trough

became established from the Philippines east-southeastward into Micronesia. Five TCs — Sally (23W), TS 24W, Tom (25W), Violet (26W), and Willie (27W) — formed in this monsoon trough. This very active monsoon trough moved northward, and became reverse oriented. By the final week of September, it had migrated to a relatively high latitude as TCs Tom (25W) and Violet (26W) carried the trough with them out of the tropics. As this monsoon trough exited the tropics, yet another monsoon trough formed at low latitudes, and was the site of development for the next two TCs in the WNP: Yates (28W) and Zane (29W).

Super Typhoon Sally (23W) was the first significant TC to form during September. Forming southwest of Guam, Sally moved on a relatively steady west-northwest straight-moving track. It became a super typhoon while moving through the Luzon Strait, and later, though weaker, it made landfall in southwestern China where it caused extensive damage and considerable loss of life. TS 24W (unnamed) began as a tropical disturbance located near Guam. By the morning of 09 September this disturbance became a large monsoon depression in the Philippine Sea. The system moved westward, crossed Luzon and entered the SCS. On 14 September, it moved into the Gulf of Tonkin where it dissipated. The upgrade to a tropical storm was based upon a post analysis of synoptic data which indicated that the sustained winds reached a peak of 45 kt (23 m/sec) when the TC was in the SCS.

The next two September TCs—
Typhoon Tom (25W) and Super Typhoon
Violet (26W) — moved in tandem along spatially-proximate recurving tracks. Although
both TCs had very large circulations, their
approximate 1100-nm (2050-km) separation
distance was too far apart for the TCs to exhibit
binary interaction. When Tom reached its peak
intensity of 75 kt (39 m/sec) on 16 September,
it had an unusual structure featuring a "pinhole" eye in a small central cloud mass surrounded by extensive peripheral rain bands
within a large outer wind field. By contrast,
Violet (located to the west of Tom) had a size
similar to Tom, and yet the structure of its core

could not have been more different: Violet's eye began small, but then became very large with a diameter on the order of 75 nm (140 km). Violet was responsible for killing seven people and injuring 44 others in southeastern Japan.

While the circulation of the large TCs Tom and Violet dominated much of the WNP, a small TC — TS Willie (27W) — developed in the Gulf of Tonkin. Never more than 90 nm (170 km) from shore, Willie circumnavigated Hainan Island while undergoing a counterclockwise loop. Willie was a small TC, and was part of a three-TC outbreak along the monsoon trough, with the larger TCs Tom and Violet to its northeast. At one point, Tom, Violet, Willie and a subtropical (ST) low existed simultaneously along the trough axis. Due to the relative motions of these TCs (and the ST low), the trough axis became reverse oriented.

The tendency of the monsoon trough of the WNP to form and then migrate northward lends itself to a natural segregation of TCs into "families" with the commonality among the TCs within each "family" being that they were associated with the same monsoon trough. The five-TC sequence of early September — Sally, TS 24W, Tom, Violet, and Willie —all had in common an origin within the same monsoon trough. By late September, this monsoon trough moved northward, became reverse oriented, and migrated to higher latitude as TCs Tom and Violet carried it with them out of the tropics. As this monsoon trough exited the tropics, a new monsoon trough formed at low latitudes, and was the site of development for the next two TCs in the WNP: Super Typhoon Yates (28W) and Zane (29W). Like Tom and Violet before them, the final two September TCs — Yates and Zane — developed in the same monsoon trough, at approximately the same time, and recurved simultaneously along similarly shaped and spatially-proximate tracks. Yates and Zane had motion characteristics suggestive of semi-direct and indirect TC interaction. The mutual anticyclonic orbit of Yates and Zane during the period 23 to 26 September (manifested in a south-of-west track for Yates) are typical of indirect TC interaction. The periods of mutual cyclonic orbit at the beginning

and at the end of the tracks is consistent with semi-direct TC interaction. It is often difficult to differentiate between semi-direct and direct TC interaction, but one clue is often the separation distance. True mutual interaction of two TCs usually occurs when the TCs are within 780 nm (1450 km) of each other. Yates and Zane were at this threshold, and it is possible that they may have interacted directly, especially at the end of their tracks when the cyclonic orbit increased rapidly.

OCTOBER

At the beginning of October, Yates and Zane recurved and moved into the midlatitudes. During this time, for about one week, the low latitudes of the WNP became relatively free of deep convection, and there was a break in TC activity. By the end of the first week of October, amounts of deep convection began to increase in the low latitudes of the WNP, and winds throughout most of Micronesia became light and variable in association with the establishment of yet another monsoon trough. Renewed deep convection (loosely organized into discrete ensembles of MCSs) was located in an east-west zone across the low latitudes of the WNP. The first three TCs of October— Abel, TD 31W, and Typhoon Beth — developed in this cloud band over the span of three days. TS Abel (30W) originated from a monsoon depression in the Philippine Sea, crossed Luzon, and became a tropical storm in the SCS. Forced to move southwestward by the northeast monsoon, it dissipated over water while approaching the coast of southern Vietnam. Moving toward the northwest, TD 31W exhibited a shear-type cloud pattern for all of its life. On 17 October, the deep convection associated with TD 31W decreased in amount and became sheared well to the east of the LLCC as the system dissipated over water. The tropical disturbance which became Typhoon Beth (32W) was first detected in the eastern Caroline Islands. For a week, it developed very slowly, and while passing over Guam, it produced a thunderstorm with a spectacular display of cloud-to-ground lightning (an unusual event in the maritime tropics). On 16 October, Beth became a typhoon in the Philippine Sea. The typhoon passed over Luzon where loss of life was reported. Encountering the northeast monsoon in the South China Sea, it turned to the southwest, weakened, and made landfall in central Vietnam.

On 17 October, three TCs were active in the western part of the WNP: Abel (in the South China Sea), TD 31W (east-southeast of Okinawa), and Beth (32W) (near the coast of Luzon). Elsewhere in the tropics of the WNP. amounts of deep convection were below normal and the low-level wind was predominantly from the east. The only area of deep convection considered to have a potential for TC formation was associated with a TUTT cell which was centered near 17°N 168°E. Typhoon Carlo (33W) formed in association with this TUTT cell. Water-vapor imagery provided detailed information on the evolution of upperlevel winds, clouds, and moisture for this event. Carlo reached its peak intensity of 105 kt (54 m/sec) while moving northward after reaching its apparent "point of recurvature": a typical behavioral characteristic of TCs which move on a north-oriented track. Accelerating to a speed of 30 kt (55 km/hr), Carlo was absorbed into the frontal cloud band of an intense extratropical low on 27 October.

In late October, TC development shifted to the SCS. On 25 October, TD 34W developed just west of the Visayan Islands of the Philippines. This small and weak TC moved to the west-southwest, and as it approached the Malay peninsula, it turned toward the northwest. TD 34W passed through the Gulf of Thailand, moved across the Isthmus of Kra into the Bay of Bengal, and then dissipated over southern Myanmar on 31 October. On the last day of the month, the monsoon depression which became TS 35W formed over the Philippines at nearly the same location at which TD 34W originated. It did not become a tropical storm until early November. As a monsoon depression, TS 35W was a larger system than TD 34W. It moved across the SCS and made landfall in central Vietnam. The upgrade to tropical storm intensity was based upon post analysis of ships reports and satellite imagery.

NOVEMBER

From late October through the first day of November, the tropics of the WNP (except the SCS) was dominated by easterly low-level wind and upper-level westerly wind. Deep convection was disorganized and widely scattered. On 02 November (the same day that TS 35W became a tropical storm in the SCS), the amount of deep convection in the low latitudes of the WNP began to increase in association with lowering pressure throughout Micronesia. This was accompanied by the onset of a nearequatorial trough along 5°N. On 03 November, the deep convection consolidated into two distinct clusters: one centered near 8°N 150°E (which became Super Typhoon Dale (36W)), and the other centered near 7°N 138°E (which became TS Ernie (37W)). Super Typhoon Dale (36W) became a large and very intense typhoon with an extensive area of monsoon gales to its south and southwest. The equatorial westerly wind burst that preceded Dale's formation was accompanied by extremely low sealevel pressure reports along the equator. Passing 110 nm (205 km) south of Guam late on 07 November, the typhoon generated phenomenal seas and surf which pounded the island for three days. Dale recurved, and on 14 November, it transitioned into an intense extratropical cyclone. TS Ernie (37W) originated from a westward moving tropical disturbance first noted on 29 October in the eastern Caroline Islands. For several days the pre-Ernie tropical disturbance moved westward before showing signs of development on 03 November. The system became a tropical storm only a few hours before making landfall in northern Mindanao. Ernie crossed the Philippines and entered the SCS where it reached its peak intensity of 50 kt (26 m/sec). While undergoing a clockwise loop west of Luzon, the system merged with TD 39W, and later moved toward the west-southwest in association with a surge in the northeast monsoon to its north. On 18 November, the weakened TC dissipated in the Gulf of Thailand.

The rest of the November TCs were weak. TS 38W (unnamed) — the third unnamed TC of 1996 in the WNP — developed

from an unusually late-in-the-year TÜTT cell located northeast of Dale. For nearly eight days (04-12 November), the system moved erratically. The TC dissipated on 12 November when it was located near 22°N 179°W, approximately 180 nm (335 km) east of where it formed late on 04 November. Late on 06 November, a tropical disturbance formed between Dale and Ernie as they were moving toward the west. This disturbance became TD 39W. Located within 200 nm (370 km) of one another, TD 39W and Ernie underwent a binary interaction that ended in merger. On 10 November, the weakened TD 39W was absorbed into the circulation of Ernie.

After Dale recurved, and Ernie and TD 39W moved into the SCS, the WNP experienced a break in TC activity associated with rising sea-level pressure (SLP) and light winds at low latitude. After a week-long lull, and although low-latitude SLP remained high, an extensive area of deep convection formed in Micronesia. On 23 November, this area of deep convection evolved into a large monsoon depression centered near Chuuk. Moving northwestward toward Guam, this monsoon depression became TD 40W. The depression moved as far north as 18°N, where it ran into a region of enhanced northeasterly low-level flow. The system then became sheared, began to drift toward the southwest, and interacted with some MCSs along its path. The weakened TC dissipated over Mindanao on 02 December.

DECEMBER

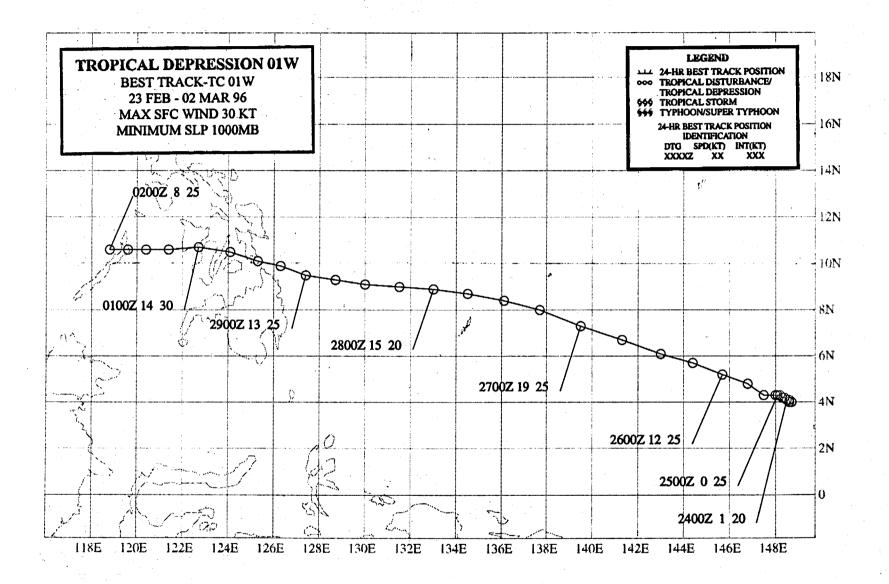
After the demise of TD 40W over the southern Philippines on 02 December, activity subsided in the WNP until 10 December when an area of deep convection formed in the SCS. On 13 December, synoptic data indicated that a weak low-level circulation center (LLCC) was located at low latitude east of the Malay peninsula in association with the deep convection in the region. The LLCC moved eastward and became TD 41W on 14 December. The depression moved eastward toward Borneo, then on December 16, as it neared the northwest coast of Borneo, it doubled back and moved west-

ward. The TC continued westward and dissipated on 21 December when located approximately 90 nm (165 km) from where it formed.

During mid-December, amounts of deep convection began to increase across Indonesia and eastward along the equator to near 160°E associated with a developing equatorial westerly wind burst (WWB). The WWB gradually strengthened and westerly winds increased to 40 kt (21 m/sec) with gusts to 50 kt (26 m/sec) extending from Indonesia to 155°E. The band of strong low-level westerly winds persisted between the axes of twin low-latitude monsoon troughs. A total of five TCs — two in the Northern Hemisphere (Fern (42W) and Greg (43W)), and three in the Southern Hemisphere (Ophelia (11S), Phil (12P), and Fergus (13P)) — formed along the respective monsoon trough axis.

Typhoon Fern (42W) formed southeast of Guam at low latitude in association with a Southern Hemisphere twin, Fergus (13P). Fern moved west-northwestward, and turned to the north on Christmas Day when it was located just west of Yap. Fern attained its maximum intensity of 80 kt (41 m/sec) on 26 December. The weakening typhoon dissipated 150 nm (280 km) northeast of Saipan on the last day of the month.

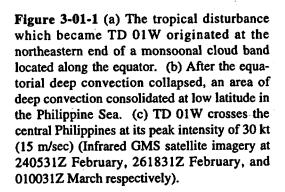
The final WNP TC of 1996, TS Greg (43W), developed in the SCS mid-way between Vietnam and Borneo. Greg moved eastward at low latitude for its entire life, apparently steered by the strong westerly winds associated with the intense WWB to its south. The TC reached its peak intensity of 45 kt (23 m/sec) on Christmas Day, and the next morning made landfall in an unusual location: the northern tip of Borneo near the city of Kota Kinabalu in the East Malaysian State of Sabah. Greg was responsible for loss of life and extensive damage to property in Sabah. At least 124 lives were reported lost with another 100 reported missing primarily due to flooding from torrential rains. Greg continued its unusual eastsoutheastward motion and dissipated on 27 December at 3°N in the eastern Celebes Sea.

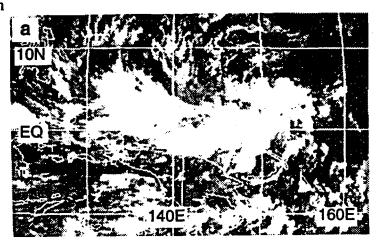


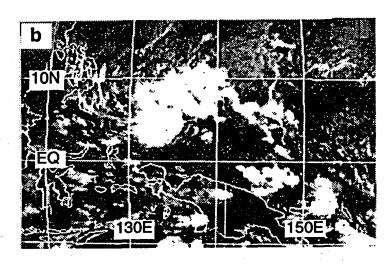
TROPICAL DEPRESSION 01W

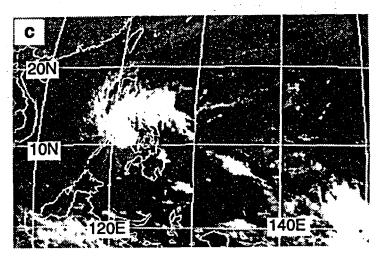
The first significant tropical cyclone (TC) of 1996 in the western North Pacific (WNP), Tropical Depression (TD) 01W formed at low latitude in a near-equatorial trough associated with a surge in the monsoonal westerlies (i.e., a westerly wind burst). The tropical disturbance which

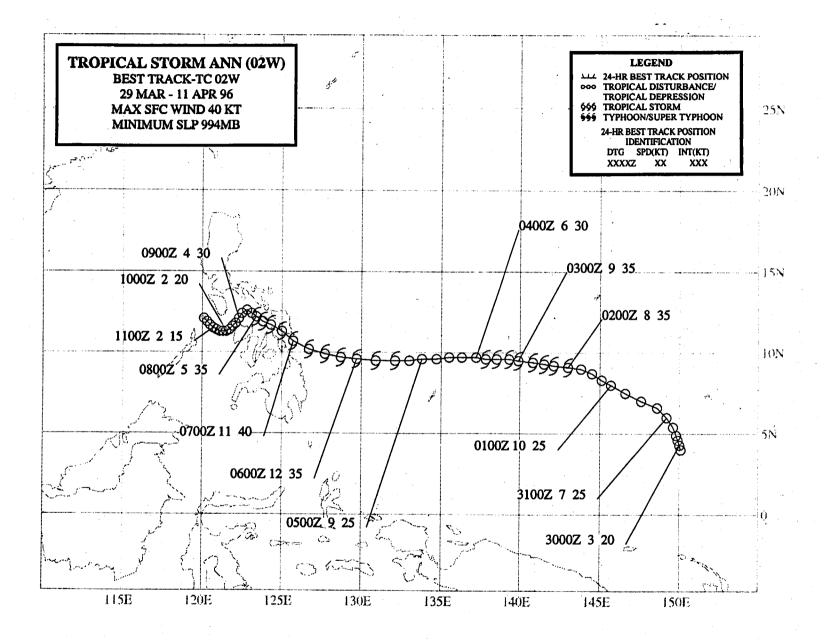
became TD 01W was first mentioned on the 230600Z February Significant Tropical Weather Advisory when satellite imagery indicated that deep convection was becoming organized on the northeastern end of a monsoonal cloud band along the equator (Figure 3-01-1a). After deep convection along the equator collapsed, a weak TC consolidated in the Northern Hemisphere, and toward westward the moved Philippines (Figure 3-01-1b). Two formation alerts (one at 281300Z and the other at 290430Z) were issued prior to the first warning valid at 290600Z February. The first warning indicated that the intensity of TD 01W was 30 kt (15 m/sec). Although forecast to slowly intensify while crossing the Visayan Island group of the central Philippines, TD 01W remained at 30 kt (Figure 3-01-1c), and then weakened as it approached the South China Sea. The final warning was issued at 011800Z March. No reports of damage or injuries were received.











TROPICAL STORM ANN (02W)

I. HIGHLIGHTS

The first named TC of 1996 in the WNP, Ann formed in the Eastern Caroline Islands. While moving westward, Ann had two peaks of intensity, one while southwest of Guam, and the other as it went ashore in the Philippines. Deep convection associated with Ann deposited as much as five inches of rain in 24 hours on parts of Guam — the value of the monthly average rainfall for this dryseason month.

II. TRACK AND INTENSITY

The tropical disturbance that became Ann was first mentioned on the 280600Z March Significant Tropical Weather Advisory. Comments on this advisory included:

"... An area of convection is located [in the Caroline Island group]. The area is located in a near equatorial trough with strong easterly trades to the north, while animated visible satellite imagery shows winds with a weak westerly component between the trough and the equator ..."

This disturbance moved steadily northwestward and fluctuations in the amount and organization of its deep convection prompted the JTWC to issue three Tropical Cyclone Formation Alerts (TCFA) prior to the first warning. The first TCFA was issued valid at 302000Z March when its deep convection became better organized. The second TCFA was issued, valid at 312000Z, when the disturbance failed to become better organized, but it was determined that conditions were still favorable for intensification. A third TCFA followed, valid at 012000Z April.

The first warning on Tropical Depression (TD) 02W was released, valid at 020000Z, when microwave imagery defined the low-level circulation and indicated the cyclone possessed wind speeds of 25 kt (13 m/sec). TD 02W was upgraded to Tropical Storm Ann 24 hours later based upon intensity estimates of 35 kt (18 m/sec) from both conventional satellite (i.e., infrared and visible) and microwave imagery. Ann was downgraded to a tropical depression at 040000Z when it became less organized in satellite imagery. A final warning was issued at 041200Z when it was thought that Ann was dissipating over water. The system was soon regenerated to TD 02W on the warning valid at 050000Z when the organization of its deep convection improved (Figure 3-02-1). On the warning valid at 050600Z, TD 02W was once again upgraded to Tropical Storm Ann. Traveling almost due westward along 10°N, Ann remained at minimal tropical-storm intensity until just before it passed through the Philippine archipelago where, at 061800Z, it reached its peak intensity of 40 kt (21 m/sec). Entering the central Philippines, Ann slowed its forward speed and dissipated as a significant tropical cyclone before it could cross into the South China Sea. The final warning was issued valid at 091200Z.

III. DISCUSSION

a. Position inaccuracies

During the five day period 010000Z through 060000Z April, the warning position (based primarily on satellite fixes) was displaced 90 to 120 nm (165 to 220 km) to the north of the final best track. The final best track for this period was placed further to the south after a careful re-examination of the synoptic data, coupled with a re-evaluation of the satellite imagery. It is not uncommon for the working best track of poorly defined, westward moving TCs at low latitude to be relocated southward in a final analysis (see the summary of Tropical Storm 35W).

b. Ann's southern twin?

As Ann moved westward toward the Philippines along 10°N, a Southern Hemisphere TC — Olivia (25S) — moved westward in near symmetry along 10°S (Figure 3-02-1). Although Ann and Olivia (25S) did not form as classical TC twins as described by Lander (1990), they were, for a short period, situated in near symmetry with respect to the equator as they both moved to the west along their respective near-equatorial trough axes. Ann later dissipated over the Philippines while Olivia recurved in the South Indian Ocean.

IV. IMPACT

No reports of damage or injuries were received. On the positive side, the peripheral rainbands of Ann contributed some much-needed dry-season rainfall to parts of the island of Guam.

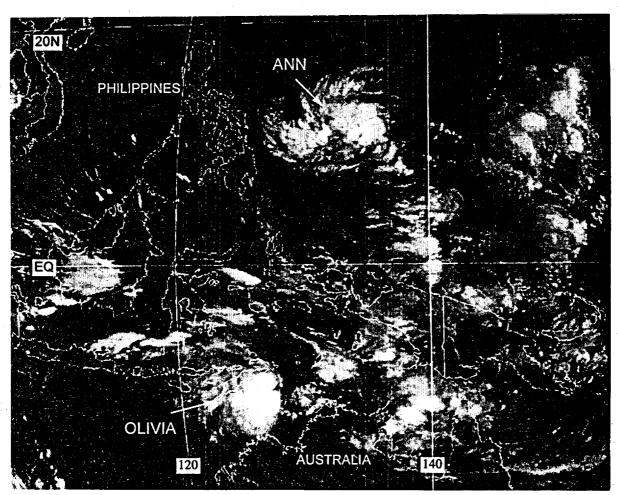
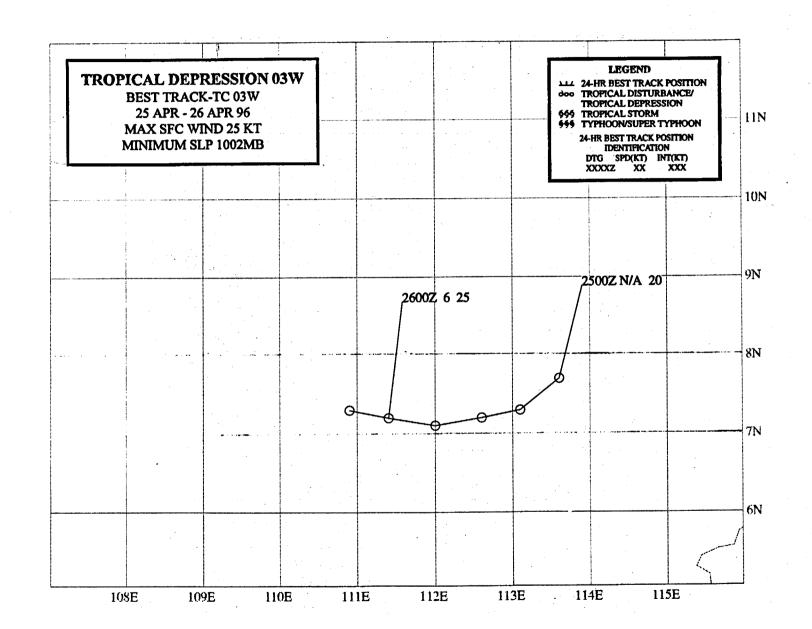


Figure 3-02-1 Tropical Storm Ann moves westward toward the Philippines in near symmetry with the westward moving TC Olivia (25S) (042224Z April infrared GMS imagery).

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TROPICAL DEPRESSION 03W

Short-lived Tropical Depression (TD) 03W was first mentioned on the 250600Z April Significant Tropical Weather Advisory when satellite imagery and synoptic data showed that a low-level circulation center (LLCC) was associated with an area of persistent deep convection northwest of Borneo (Figure 3-03-1). As the persistent deep convection became better organized, and SSM/I-derived wind speeds of 30 kt (15 m/sec) were observed north and west of the LLCC, the JTWC issued a Tropical Cyclone Formation Alert, valid at 250900Z. Ship reports and satellite intensity estimates indicating wind speeds of 25 kt (15 m/sec) near the LLCC prompted the JTWC to issue the first warning on TD 03W, valid at 251200Z. TD 03W was short-lived, however, and the final warning was issued, valid at 260900Z, when the deep convection became disorganized.

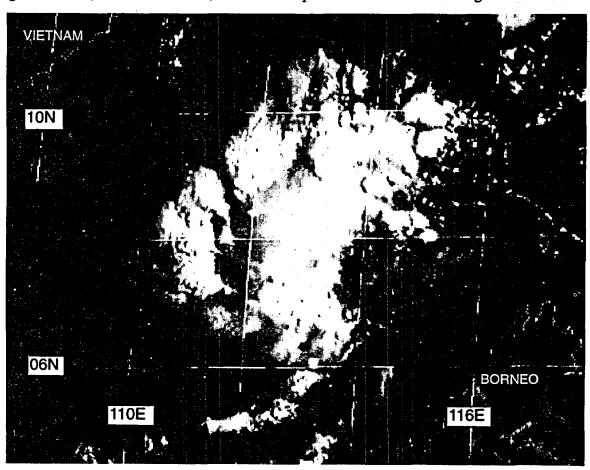
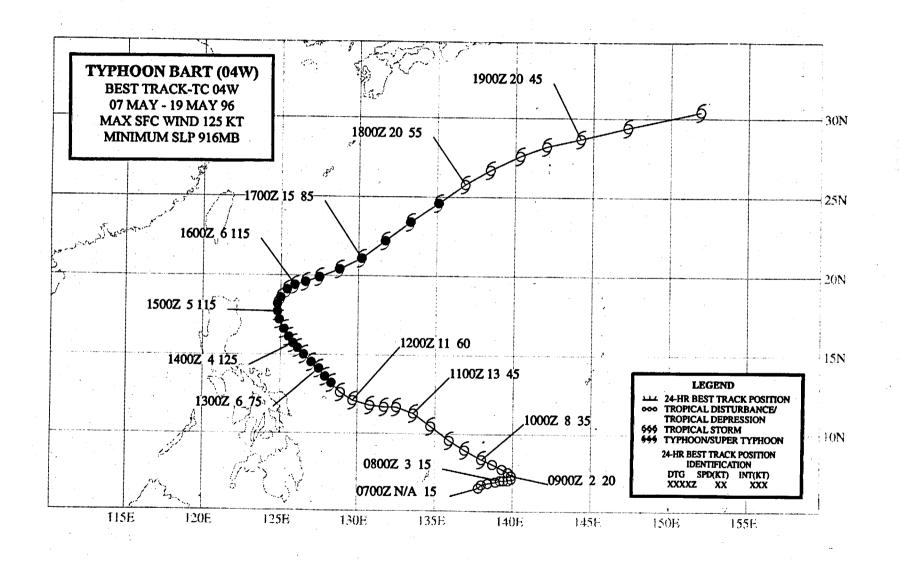


Figure 3-03-1 In the genesis stage of TD 03W, deep convection becomes loosely organized into a cyclonically curved band north and west of a partially exposed LLCC (250331Z April visible GMS imagery).



TYPHOON BART (04W)

I. HIGHLIGHTS

Bart was the first western North Pacific (WNP) TC of 1996 to reach typhoon intensity. It became a very intense typhoon, peaking at 125 kt (64 m/sec). Initially moving toward the Philippines, it turned to the north and remained at sea. Pronounced diurnal variations in Bart's central deep convection were noted.

II. TRACK AND INTENSITY

During the first week of May, the tropics of the WNP were dominated by low-level easterly wind flow accompanied by westerly wind flow aloft. A zonally-oriented band of convection stretched east-west across Micronesia south of 10°N. This convection was highly sheared from the west, and possessed a structure more characteristic of the convergence-zone cloud band that normally dominates the central North Pacific; that is, a linear band of disorganized mesoscale convective systems located along the confluence line of the northeast and southeast trades. This synoptic regime slowly changed, and by 05 May, monsoonal low-level westerly winds had penetrated into the WNP eastward to 140°E and south of 5°N. Accompanying the arrival of the monsoonal westerlies, amounts of deep convection increased in the southern portion of the Philippine Sea, and the cirrus outflow from this region became organized into a pattern indicative of an anticyclone aloft.

As amounts of deep convection began to increase in this area, the region of persistent deep convection that became Bart was first noted on the Significant Tropical Weather Advisory valid at 050600Z May. Remarks on the advisory included:

"Convective activity (near 4°N 136°E) has increased.... Visible satellite imagery and synoptic data indicate the presence of a weak circulation beneath diffluent upper-level winds. Surface and gradient level (3000 ft) analysis indicate 10-knot westerly winds along the equator enhancing surface convergence.... Minimum sea level pressure is estimated to be 1007 mb...."

For the next four days, this disturbance — which now possessed the characteristics of a monsoon depression (see definitions section) — was slow to gain organization (e.g., well-defined low-level cloud lines, and persistent central convection). Based upon satellite imagery showing the system had acquired a small area of persistent central deep convection associated with well-defined low-level cloud lines, a Tropical Cyclone Formation Alert (TCFA) was issued valid at 090300Z May. Shortly after the TCFA was issue, cloud-top temperatures of the area of central deep convection became colder on infrared satellite imagery, and the first warning on Tropical Depression (TD) 04W was issued valid at 090600Z. Based upon indication of some shearing from the east, and implications of the structure of the system (i.e., a monsoon depression), a slower than normal rate of intensification was forecast.

Eighteen hours later (100000Z), TD 04W was upgraded to Tropical Storm Bart, based upon an improved satellite signature (an increase in the areal extent of very cold central convection), and upon the indication of 35-kt (18-m/sec) surface wind speeds from microwave imagery. A gradual turn from a westward motion to a more northward track was indicated on this warning — a track that would now spare the Philippines a landfall. With relatively low environmental shear, Bart was now forecast to intensify at a normal rate and become a typhoon in 48 hours (i.e., at 120000Z).

Evolving a classic banding-type eye (Dvorak, 1984) (see definitions section), Bart was upgraded to a typhoon at 121200Z. After becoming a typhoon, Bart began to intensify more rapidly, and reached its peak intensity of 125 kt (64 m/sec) at 140000Z (Figure 3-04-1). The estimated fall

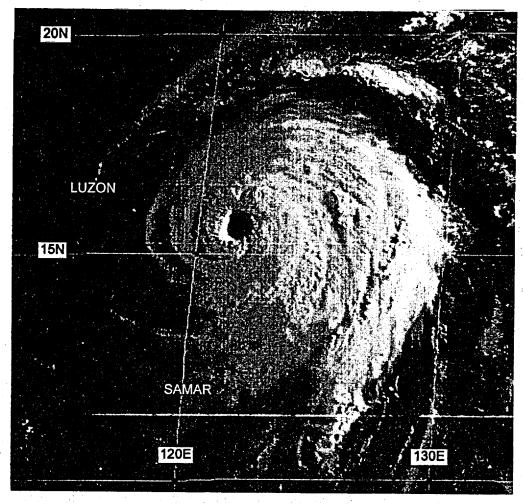


Figure 3-04-1 Bart reaches its peak intensity (132131Z May GMS visible imagery).

of central pressure of 52 mb during the 24-hour period, 130000Z to 140000Z, was sufficient to be classified as rapid intensification (Holliday and Thompson, 1979) (see definitions section).

Twenty-four hours after reaching peak intensity (i.e., at 150000Z), Bart reached its point of recurvature at 18°N, which is the climatological mean latitude of recurvature during May (Shanghai Typhoon Institute, 1990). Following recurvature at 150000Z, Bart did not begin to significantly accelerate until after 170000Z. Also during this period of slow east-northeast motion, its intensity fell only gradually. As Bart began to accelerate on 17 May, its intensity began to decrease — falling below typhoon intensity after 171800Z. On 18 May, its speed of forward motion increased to 20 kt (37 km/hr), and Bart began to shear while undergoing extratropical transition. The final warning was issued valid at 181800Z as Bart lost all its central deep convection and completed its extratropical transition.

III. DISCUSSION

Use of digital Dvorak (DD) numbers

One of the utilities installed in the MIDDAS satellite image processing equipment is an automated routine for computing Dvorak "T" numbers for TCs that possess eyes. The routine, developed by Zehr (personal communication) and programmed by Schaeffer (personal communication), adapts the rules of the Dvorak technique as subjectively applied to enhanced-infrared imagery (Dvorak, 1984) in order to arrive at an objective T number, or "digital Dvorak" T number (hereafter

referred to as DD numbers). Infrared imagery is available hourly from the GMS satellite, and hourly DD numbers were calculated for all of the typhoons of 1996.

The DD numbers presented herein are experimental, and methods for incorporating them into operational practice are being explored. In some cases, the DD numbers differ substantially from the warning intensity and also from the subjectively determined T numbers obtained from application of Dvorak's technique. The output of the DD algorithm, when performed hourly, often undergoes rapid and large fluctuations. The fluctuations of the DD numbers may lay the ground work for future modifications to the current methods of estimating tropical cyclone intensity from satellite imagery. The discussion of the behavior of the time series of the DD numbers for Bart, and for some of the other typhoons of 1996, is intended to highlight certain aspects of the DD time series that may prove to have important research and/or warning implications.

In Dvorak's 1975 and 1984 papers, he advises that the intensity estimation from satellite imagery be made at 24-hour intervals in order to remove any possible diurnal cycles that the TC might be undergoing. Dvorak further claims that the intensity of a TC is not influenced by diurnal changes in the central convection. Diurnal variations of convection reported to occur in TCs are similar to those reported to occur over the marine tropics in general: a peak in the amount of very cold cloud tops during the early morning hours with warmer cloud-top temperatures during the afternoon (Dvorak, 1985; Zehr, 1992). Observations by Black and collaborators (e.g., Black, 1983;

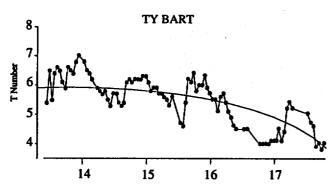


Figure 3-04-2 Bart's DD time series for the period 131030Z May through 171530Z May.

DIURNAL CYCLE OF BART'S DD

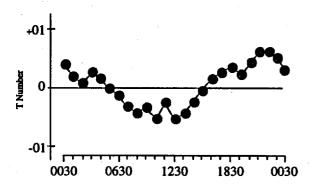


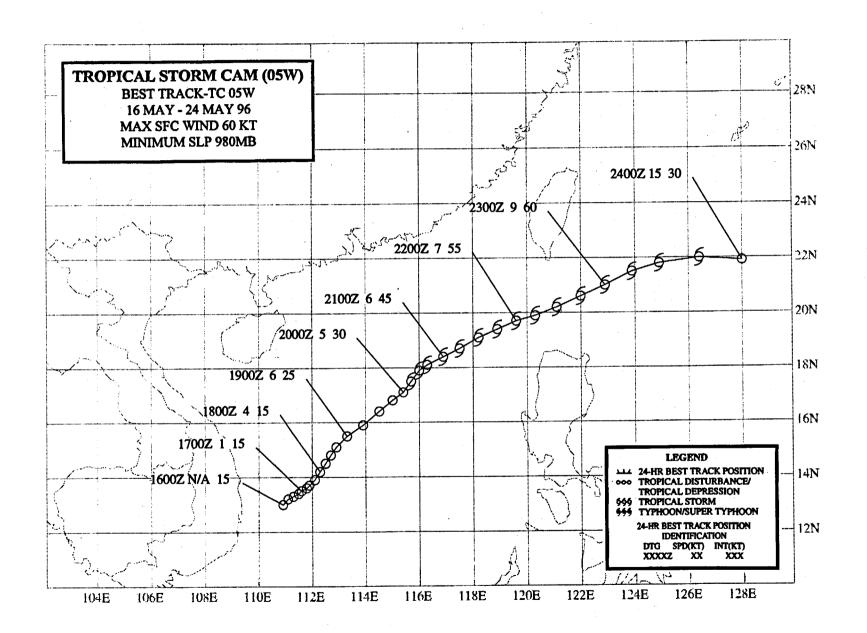
Figure 3-04-3 The diurnal cycle of Bart's DD time series as obtained by averaging the DD numbers at each hour during the period 131030Z May through 160930Z.

Black et al., 1986; Black and Marks, 1987) show that major cold convective eruptions in TCs tend to be initiated in the early morning.

Bart is one of only a few cases during the past two years in which a strong diurnal cycle can be found in the time series of its DD numbers (Figure 3-04-2). Although the DD number is based upon both the cloud-top temperature of the eye-wall cloud and the temperature within the eye, the strong diurnal cycle in Bart's DD time series (Figure 3-04-3) is certainly linked to a diurnal cycle of the eye-wall cloud-top temperatures. The DD time series of Bart has an unusually strong diurnal cycle when compared with those of other typhoons of 1996 and with those typhoons of 1995 for which the DD time series was compiled (see the 1995 ATCR). Consistent with Dvorak's rules. Bart's warning and best track intensities do not contain the large diurnal fluctuations that appear in its DD time series.

IV. IMPACT

No reports of significant damage or injuries were received at the JTWC.



TROPICAL STORM CAM (05W)

I. HIGHLIGHTS

Originating from a monsoon depression in the South China Sea (SCS), Cam moved toward the east-northeast for its entire life. While at peak intensity, it passed through the Luzon Strait and then slowly weakened as it drifted eastward into the Philippine Sea and dissipated.

II. TRACK AND INTENSITY

As Typhoon Bart (04W) was moving eastward while located south of Japan, cloudiness began to increase in the southwesterly monsoon flow across the SCS and extended east-northeast-ward toward Bart. Most of the deep convection associated with this monsoon flow was located within the SCS in the form of a large ensemble of mesoscale convective systems (MCS). The ensemble of MCSs showed some signs of low-level organization around a weak low-level cyclonic circulation, and extensive cirrus outflow indicative of anticyclonic outflow aloft. These structural attributes are typical of a monsoon depression (see Appendix A and the Discussion). The system was first mentioned on the Significant Tropical Weather Advisory valid at 170600Z May. Remarks on this advisory included:

"... An area of convection is located [in the South China Sea].... Satellite imagery and synoptic data indicate an area of strong convergence being driven by monsoon flow in a sharp trough..."

The organization of the deep convection within this monsoon depression slowly improved, and a Tropical Cyclone Formation Alert was issued valid at 181630Z. The broad circulation center of this system, as defined by low-level cloud lines and by the center of symmetry of the extensive circus outflow, appeared to be drifting very slowly toward the northeast.

Further improvements in the low-level organization coupled with a consolidation of persistent convection closer to the low-level circulation center (Figure 3-05-1) prompted the JTWC to upgrade the system to Tropical Depression (TD) 05W on the warning valid at 181800Z. Slow northeastward motion was occurring (and was forecast to continue), as deep southwesterly monsoonal flow dominated the steering.

During the daylight hours of 20 May, the convection near the center of TD 05W increased and deepened (i.e., expanded and became colder on infrared satellite imagery). The primary and peripheral cloud bands became more tightly curved and better organized around the low-level circulation center (LLCC) (Figure 3-05-2). Given these improvements in the satellite signature, TD 05W was upgraded to Tropical Storm Cam on the warning valid at 200600Z. Motion continued toward the northeast under the influence of southwesterly steering that was dominated by strong monsoon southwest winds to the south of the system.

Continuing on a relatively slow east-northeast track, Cam intensified. The peak intensity of 60 kt (31 m/sec) occurred as Cam moved through the Luzon Strait on the morning of 23 May. At this time, infrared satellite imagery (Figure 3-05-03a) indicated a tightly wound primary cloud band, and visible satellite imagery (Figure 3-05-03b) indicated the presence of a ragged eye.

After passing through the Luzon Strait, Cam accelerated eastward within deep westerly flow in the subtropics. It also weakened under the influence of westerly shear. The final warning was issued valid at 240000Z as the remnants of Cam entered the mei-yu front (which stretched eastward from Taiwan) and dissipated.

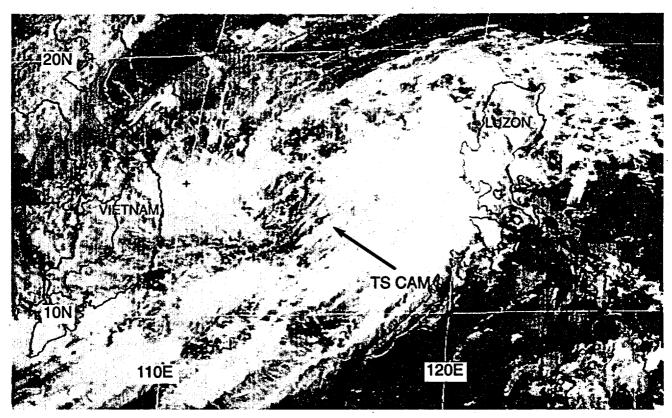


Figure 3-05-1 Near the time of the first warning, the disturbance that became Cam is organized as a monsoon depression (182331Z May visible GMS imagery).

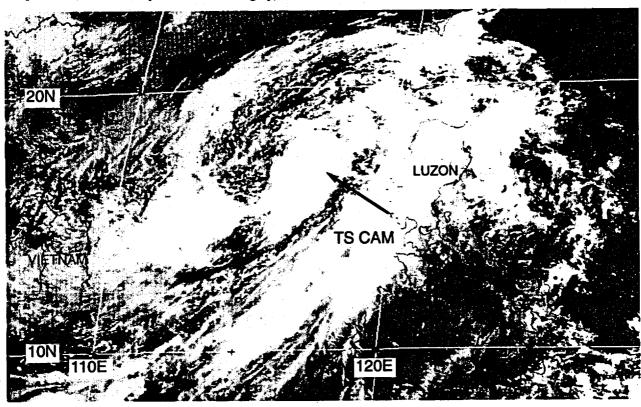
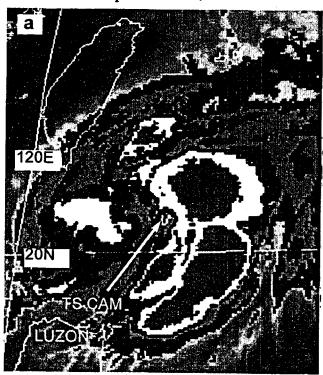


Figure 3-05-2 Deep convection has consolidated near the low-level circulation center marking the transition of the pre-Cam monsoon depression into a tropical storm (192331Z May visible GMS imagery).

III. DISCUSSION

a. The Monsoon Depression

Dvorak (1975, 1984) developed techniques for estimating the intensity of TCs from satellite imagery. His techniques are now used worldwide. The TC pattern types identified by Dvorak will be referred to as conventional TCs. In the Dvorak classification scheme, persistent deep convection must be located near the LLCC in order to initiate classification. The intensity of the TC is determined by several properties of the deep convection (e.g., the proximity of the low-level circulation center to the deep convection, the size of the central dense overcast, the cloud-top temperatures and



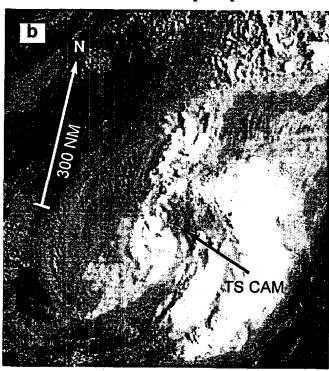


Figure 3-05-3 Cam at peak intensity: (a) 222331Z May enhanced infrared GMS imagery, and (b) 222331Z May visible GMS imagery.

horizontal width of the eye wall cloud, the width and extent of peripheral banding features). The basic TC data types identified by Dvorak are:

- 1) the "curved band" pattern (Figure 3-05-4a, b);
- 2) the "shear" pattern (Figure 3-05-4c, d);
- 3) the "central dense overcast" pattern (Figure 3-05-4e, f); and,
- 4) the "eye" pattern (Figure 3-04-4g, h).

This set of basic TC data types comprise the suite of conventional TCs.

Some conventional TCs that form in the WNP start out as monsoon depressions. The monsoon depression is a type of cyclone in the tropics that differs in several ways from the conventional types of TCs as described in Dvorak's work. The canonical monsoon depression forms over the northern Bay of Bengal in summer, and tracks west-northwestward across northeastern India (Ramage, 1971). These monsoon depressions have been studied for decades (e.g., Ramanathan and Ramakrishnan, 1932; Desai and Koteswaram, 1951; and Ramaswamy, 1969). Later, it was realized that monsoon depressions with structures similar to those of the Indian monsoon depressions occur in the Australian tropical region (Davidson and Holland, 1987), in the tropics of the western North

Pacific (JTWC, 1993), and over the deep tropics of Africa. The monsoon depression differs from conventional TCs in some respects:

- 1) very large size (the outer-most closedisobar may have a diameter on the order of 1000 km);
- 2) a lack of persistent deep convection near the LLCC (most of the deep convection in monsoon depressions is loosely organized in clusters or bands displaced from a few to several hundred kilometers from the low-level circulation center); and,
- 3) a low-level wind distribution that features a 200-km diameter light-wind core which may be partially surrounded by areas of gales or even storm force winds.

Because of the structure of monsoon depressions (e.g., their lack of persistent central deep convection), the use of Dvorak's techniques to estimate their intensity may be a misapplication. When applied to monsoon depressions, Dvorak's techniques yield intensities which are below the maximum winds that are usually present in areas displaced a few hundred kilometers from the LLCC. The intensity estimates yielded by Dvorak's techniques for monsoon depressions may, however, be representative of the lighter winds near their LLCCs.

Figure 3-05-4 Schematic illustration (left column) and representative satellite imagery (right column) of Dvorak's (1975) basic tropical cyclone data types: (a,b) the "curved band" pattern; (c,d) the "shear" pattern; (e,f) the "central dense overcast" pattern; and, (g,h) the "eye" pattern.

Monsoon depressions can evolve into conventional TCs. As they slowly intensify, many monsoon depressions observed over the WNP eventually acquire persistent central deep convection and become conventional TCs. An unresolved question remains concerning the transition of a monsoon depression into a conventional TC: does the monsoon depression become the conventional TC, or does a conventional TC form within the circulation of the monsoon depression?

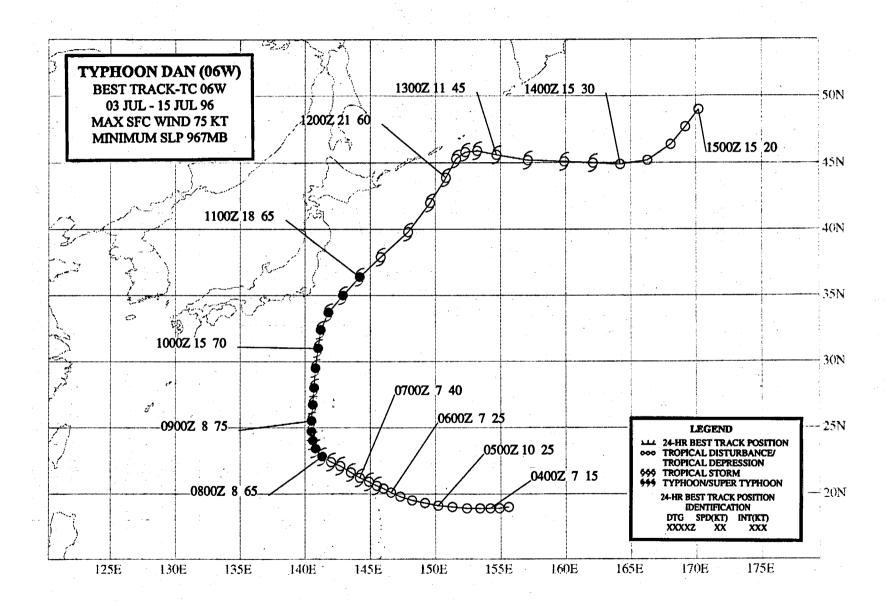
Cam began as a monsoon depression in the South China Sea. Initially it was a large ensemble of mesoscale convective systems embedded within a region of lowered sea-level pressure. It lacked persistent central deep convection, and the maximum winds in the system were displaced outward from the low-level circulation center, particularly to the south where monsoonal flow was strong. Eventually, as the system moved toward the northeast, circulation intensified and persistent central deep convection became established, marking its transition to a conventional TC.

b. Unusual motion

Persistent eastward motion of a TC at low latitude is unusual. Cam moved eastward for its entire track: forming near 13°N in the South China Sea it moved slowly toward the east-northeast for its entire track and eventually dissipated in the subtropics at 22°N. Most cases of eastward motion of a TC at low latitude in the WNP can be attributed to the influence of the monsoon circulation on the steering flow. In Cam's case, the deep southwesterly monsoon flow to its south was, for much of its track, the dominant flow asymmetry responsible for its northeastward motion. Monsoonal influences on TC motion form an important part of Carr and Elsberry's "Systematic and Integrated Approach" to TC forecasting (see Chapter 1).

IV. IMPACT

No reports of significant damage or injuries were received at the JTWC.



TYPHOON DAN 06W

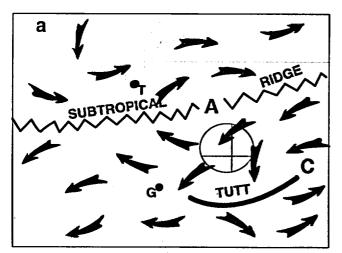
I. HIGHLIGHTS

After Cam (05W) dissipated in the mei-yu front during the last week of May, there were no significant TCs in the WNP until early July when Dan formed. The tropical disturbance which became Dan was associated with the tropical upper-tropospheric trough (TUTT) and with cyclonic circulations (TUTT cells) within it. Scatterometer data received on 07 July resulted in JTWC doubling the radius of gales on the warning, and ship reports of 60 kt (31 m/sec) provided crucial ground truth for the intensity after Dan recurved and was becoming extratropical.

II. TRACK AND INTENSITY

During June, the WNP tropics were inactive. There were no significant TCs, amounts of deep convection were below normal, low-level winds were anomalously easterly and upper-level winds were anomalously westerly (Climate Prediction Center (CPC), 1996). In early July, the Southwest Monsoon remained inactive in the WNP with large-scale climatic wind anomalies similar to those of June. The tropical disturbance which became Dan was associated with the TUTT (see the discussion section), and first appeared as an inverted trough in the low-level easterly flow (Figure 3-06-1a, b). This disturbance was first mentioned on the 031700Z July Significant Tropical Weather Advisory. This advisory included the comments:

"... An area of convection is located near 21N 155E. Satellite imagery and synoptic data indicate a closed circulation exists within a... TUTT. Animated infrared satellite imagery indicates the circulation of this TUTT cell has likely built down to the mid-levels of the atmosphere. Convection near the center of the TUTT cell has improved over the past 6 to 12 hours...."



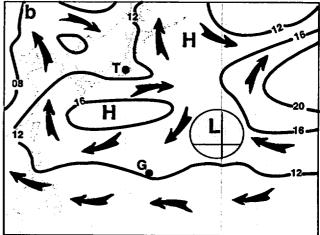


Figure 3-06-1 (a) An area of deep convection (shaded circle) forms in the diffluent northeasterly flow between the axis of the TUTT and the subtropical ridge at 200 mb. (b) At the surface, the area of deep convection (shaded circle) is associated with an inverted trough in the easterly flow southwest of a subtropical high. Arrows depict wind direction, A = anticyclone, C = TUTT cell, L = low pressure, G = Guam, and T = Tokyo. Analyses are adapted from the 021200Z July NOGAPS 200-mb and SLP products.

When synoptic data showed that a low-level cyclonic circulation was located beneath an area of organized deep convection, the JTWC issued a Tropical Cyclone Formation Alert, valid at 041951Z. At this time, the LLCC and most of the deep convection were located to the northeast of

a TUTT cell. The first warning on Tropical Depression (TD) 06W was issued, valid at 050000Z, based upon satellite intensity estimates of 25 kt (13 m/sec).

Dan intensified to a tropical storm at 061200Z, and at 080000Z became a typhoon (Figure 3-06-2). A scatterometer pass over the cyclone at 071304Z (Figure 3-06-3) resulted in a large increase in the radius of gales reported on the warning valid at 071800Z (see the discussion). After becoming a typhoon, Dan turned toward the north and reached its peak intensity of 75 kt (39 m/sec). Moving on a poleward-oriented track, Dan's intensity changed very little for three days following the peak: at 100000Z the intensity was 70 kt (36 m/sec), at 110000Z it was 65 kt (33 m/sec), and at 120600Z it was still at 60 kt (31 m/sec) despite reaching 45°N.

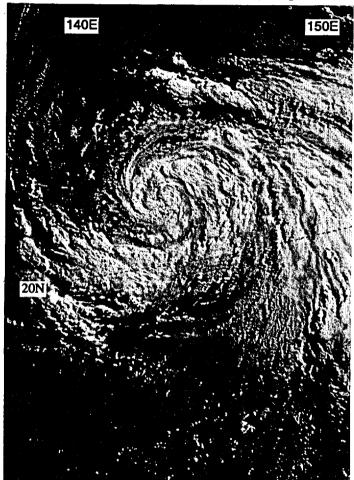


Figure 3-06-2 Dan becomes a typhoon (072040Z July visible DMSP imagery).

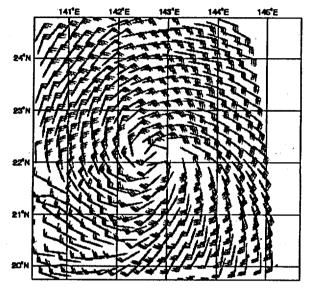


Figure 3-06-3 Scatterometer-derived wind speeds in a swath that passed over Dan (071304Z July ERS-2 scatterometer-derived marine surface wind speeds). This product was used in real time to expand the area of gales on the TC warning.

After 111200Z, satellite intensity estimates began to fall. Based on synoptic data, intensity estimates of Dan after 111200Z were kept significantly higher than satellite intensity estimates (Table 3-06-1). The problem of dropping the satellite intensity estimates far too low as a TC becomes extratropical is long-standing. During 1996, JTWC

satellite analysts developed and implemented a new technique for estimating the intensity of TCs which are undergoing extratropical transition (Miller and Lander, 1996) (see the discussion).

The JTWC issued the final warning on Dan, valid at 120600Z, as the system moved eastward and completed its extratropical transition.

III. DISCUSSION

a. TUTT-related genesis

Dan (06W) originated and developed in association with a TUTT cell. Typical of TCs which develop in association with TUTT cells, Dan formed at a relatively high latitude (20°N), and as Figure 3-06-1 indicates, the system developed in the low-level easterly flow on the southwest flank of a subtropical high. For a more complete discussion of TUTT-related TC genesis, see Carlo's (33W) summary. In Carlo's (33W) case, and also in the case of Joy (12W), water-vapor imagery very clearly depicted the process of TC genesis associated with a TUTT cell. The formation of Dan (and also of Eve (07W)) in association with TUTT cells was more complicated than that of Carlo (33W) or Joy (12W), and its description is beyond the scope of this summary.

b. Scatterometer aids diagnosis of wind distribution

On the warning valid at 071800Z, the radius of 35-kt (18-m/sec) wind was nearly doubled from its value on the warning valid at 071200Z. This large change in the wind radius was based upon scatterometer data from the European Remote Sensing Satellite-2 (ERS-2) (Figure 3-06-3). Comments on the 071800Z warning included:

"... The most significant change in this warning compared to the previous warning is the sudden change of wind radii, which is based on satellite scatterometry data from an overhead pass of the European ERS-2 polar orbiter..."

The JTWC has access to scatterometer wind data, and has used it to help determine the position, intensity and wind distribution of TCs. Some drawbacks of the scatterometer data are its small swath width, 180° directional ambiguity, relatively coarse resolution, an upper limit on the wind speeds that it can accurately detect, and a low-speed bias. For a more detailed discussion of scatterometer data, see Rick's (22W) summary.

c. On the intensity of TCs undergoing extratropical transition: the "XT" technique

For many years, the JTWC has had a problem diagnosing the intensity of TCs as they undergo extratropical transition. In general, the application of Dvorak's techniques to these systems has resulted in intensity estimates that are significantly lower than what is reported by ships or land stations. An extreme example of this problem occurred during the approach of Seth (1994) to Korea which is highlighted in Seth's summary in the 1994 ATCR. Dan provided another good example of this problem: as it was becoming extratropical (Figure 3-06-4), the satellite intensity estimates fell to values that were later proven to be far too low when compared to ship reports (Table 3-06-1). Attempts to apply Hebert and Poteat's (1975) techniques for estimating the intensity of subtropical cyclones to these systems were not successful.

In order to address the problem of underestimating the intensity of TCs undergoing extratropical transition, satellite analysts at the JTWC in conjunction with ONR-supported researchers at the University of Guam devised a technique (Miller and Lander, 1996) for estimating the intensity of TCs undergoing extratropical transition. This technique yields XT (for extratropical transition) numbers that equate to wind speeds identical to Dvorak's T numbers of the same magnitude. The technique also defines the completion of extratropical transition. On the few independent cases for which it was applied during 1996 the technique appears to have worked well. Though operational, the technique may be refined as more cases are examined. Specific details are beyond the scope of this summary, and those interested are invited to request a copy of the Miller and Lander (1996) technique.

IV. IMPACT

Skirting east of Japan, Dan drenched the Tokyo metropolitan area with over 5 inches of rain, and over twice that much in the adjoining Chiba prefecture. High water stalled trains and flooded streets. In Chiba prefecture, 29 houses were evacuated and at least 200 were reported damaged by flooding.

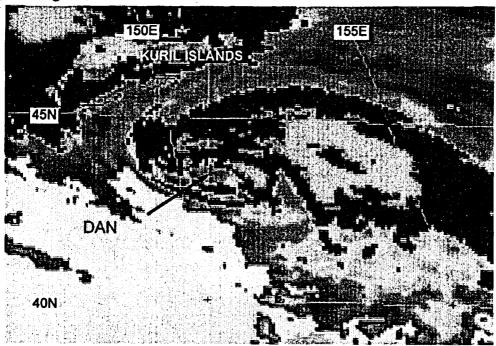
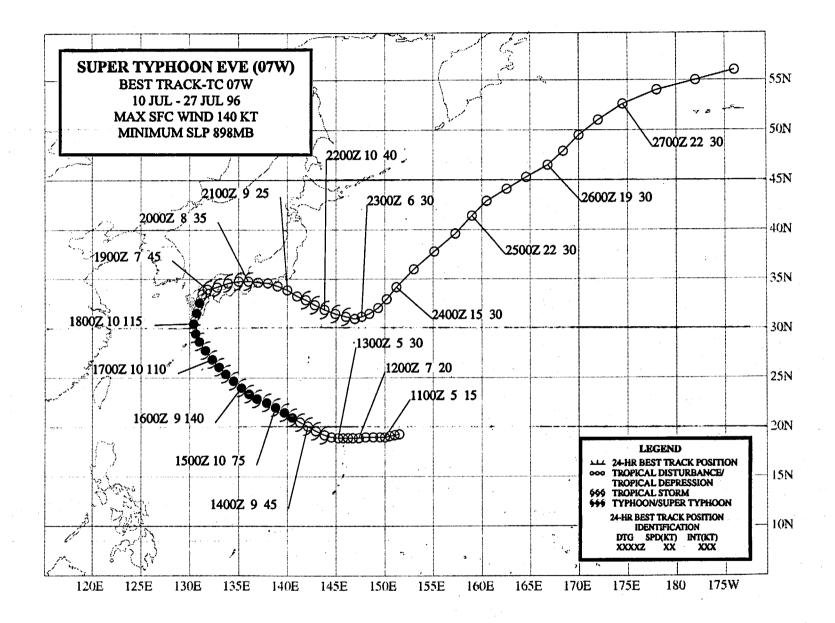


Figure 3-06-4 Dan begins its extratropical transition. Satellite intensity estimates as low as 35 kt (18 m/sec) at this time were far lower than ship reports of 60 kt (31 m/sec) used to support the best-track intensity (112031Z July enhanced infrared GMS imagery).

Table 3-06-1 Intensity estimates derived from satellite imagery during Dan's extratropical transition. In the code, T = Dvorak tropical numbers, ST = Hebert and Poteat subtropical numbers, and the number that follows the "/" is the current intensity which is always held higher when the TC is weakening over water.

			Best Track
Time (Z)	Code	Intensity (kt)	Intensity (kt)
101430	T 2.5/3.5	55	65
101432	T 2.5/3.5	55	65
101730	T 2.5/3.0	45	65
102014	T 2.5/3.0	45	65
102032	T 2.0/3.0	45	65
102330	T 2.5/3.5	55	65
110230	T 2.0/3.0	45	65
110407	T 2.5/3.0	45	60
110530	T 2.5/3.5	55	60
110717	T 2.5/3.0	45	60
110830	T 2.5/3.5	55	60
110832	T 1.5/2.5	35	60
111130	T 2.5/3.0	45	60
111432	T 2.0/2.5	35	60
112030	T 2.0/2.5	35	60
112002	ST 2.5/2.5	35	60
112032	T 2.0/2.0	30	60
112330	ST 3.0/3.0	45	60
120530	ST 3.0/3.0	45	60
120703	T 0.5/1.0	25	60
120830	ST 3.0/3.0	45	60



SUPER TYPHOON EVE (07W)

I. HIGHLIGHTS

Eve, like Dan (06W) which preceded it, originated in association with a TUTT cell. After undergoing explosive deepening, Eve became the first WNP super typhoon of 1996. The typhoon passed through the northern Ryukyu Islands and made landfall in southern Japan. Moving eastward over Japan, the system weakened before intensifying to tropical storm intensity after moving offshore.

II. TRACK AND INTENSITY

As Dan was recurving to the east of Japan, a TUTT cell formed to its southeast. A band of deep convection formed a "U" shape to the south of this TUTT cell (Figure 3-07-1). Although not mentioned until 120600Z July on the Significant Tropical Weather Advisory, the disturbance which

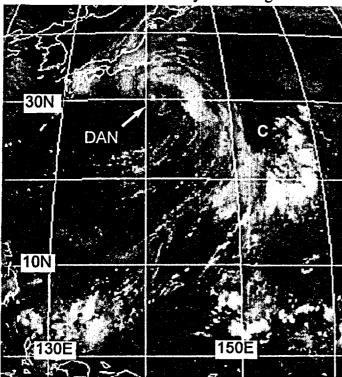


Figure 3-07-1 The tropical disturbance that became Eve originated from an area of deep convection to the south of a TUTT cell (C). This TUTT cell was, in turn, located to the southeast of the recurving Dan (06W) (091831Z July infrared GMS imagery).

became Eve was tracked in post analysis back to the place where, at 100600Z, it consolidated in the TUTT-related area of deep convection. On 13 July, an area of persistent deep convection located about 300 nm (550 km) to the north of Guam, began to show signs of increasing organization. Synoptic data indicated that a low-level cyclonic circulation was located within this area of deep convection, and the JTWC issued a Tropical Cyclone Formation Alert valid at 130800Z July. During the night of 13 July, the persistent area of deep convection became well-organized, and satellite intensity estimates of 25 kt (13 m/sec) (later adjusted to 35 kt (18 m/sec) in post analysis) prompted the JTWC to issue the first warning on Tropical Depression (TD) 07W, valid at 131200Z.

When Eve formed a beautiful banding eye on the morning of 15 July (Figure 3-07-2), it was upgraded to a typhoon on the warning valid at 150000Z. From 150000Z to 160000Z, Eve underwent a period of explosive deepening (see the discussion section). At 151800Z, it became a super typhoon, and

at 160000Z it reached its peak intensity of 140 kt (72 m/sec) (Figure 3-07-3). Forming concentric wall clouds (Figure 3-07-4), the intensity decreased to 100 kt (51 m/sec) by 170600Z. Just prior to making landfalling at Kyushu, Japan, on 18 July, the eye once again became small and well defined, and the intensity increased to 115 kt (59 m/sec). The system made landfall at approximately 180300Z and began to weaken over the mountainous terrain of Kyushu. The system was downgraded to a tropical storm at 191200Z, and the final warning was issued, valid at 200000Z, as the system moved eastward over the main Japanese island of Honshu and weakened.

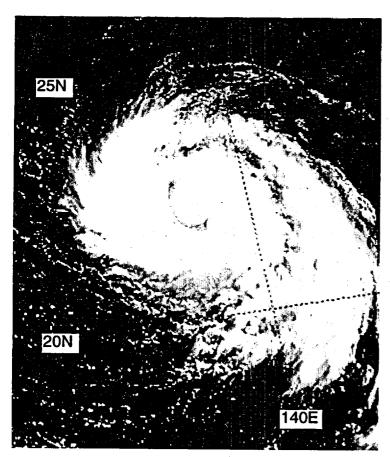
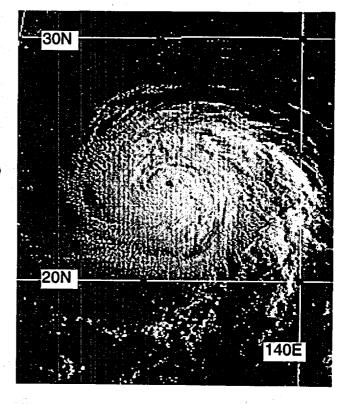


Figure 3-07-2 Eve forms a text-book quality banding eye pattern (150019Z July visible DMSP imagery).

Figure 3-07-3 Eve at its peak intensity 140 kt (72 m/sec) (152131Z July visible GMS imagery).



When the system moved over water to the east of Japan, it regenerated. A post analysis of synoptic data, and a reanalysis of satellite imagery (e.g., Figure 3-07-5), supported a regeneration to tropical-storm intensity for the 24-hour period 211200Z to 221200Z, with a maximum intensity of 40 kt (21 m/sec) at 211800Z. After 251200Z, all deep convection was sheared away from the LLCC, marking the completion of extratropical transition. The system was identifiable on satellite imagery as it tracked all the way to the Aleutian Island chain where hourly data from Shemya (WMO 70414) indicated a small pressure fall and a wind shift attributable to the remnants of Eve passing to the southeast on 27 July.

III. DISCUSSION

a. TUTT-related genesis

Eve, like Dan (06W) which preceded it by a week, originated in association with a TUTT cell. Typical of TCs which develop in association with TUTT cells, Eve formed at a relatively high latitude (20°N), and it formed in the cloud-minimum region north of the cloudiness associated with the monsoon trough. For a more complete discussion of TUTT-related TC genesis, see Carlo's (33W) summary. In Carlo's (33W) case, and also in the case of Joy (12W), water-vapor imagery very clearly depicted the process of TC genesis from a TUTT cell.

b. Explosive deepening

Between 150000Z and 160000Z July, Eve's intensity increased from 75 kt (39 m/sec) to 140 kt (72 m/sec). The equivalent 24-hour pressure fall (using Atkinson and Holliday's (1977) wind-

pressure relationship) was 70 mb, resulting in an average decrease of 2.92 mb/hr. This rate of pressure fall easily qualifies as a case of explosive deepening which is described by Dunnavan (1981) as a decrease in the minimum sea-level pressure of a TC of 2.5 mb/hr for at least 12 hours or 5 mb/hr for at least six hours. If one honors the digital Dvorak (DD) time series at this time (Figure 3-07-6), the rate of intensity increase is even more remarkable: the DD numbers at 150000Z were on the order of T 4.5, and then rose to their peak of approximately T 7.5 at 151800Z. The equivalent pressure fall using the DD

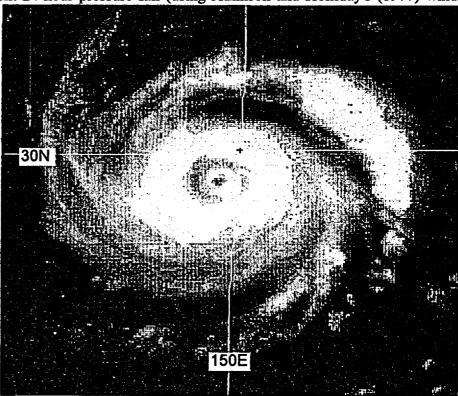


Figure 3-07-4 Shortly after reaching its peak intensity, Eve formed concentric eye walls. The relatively cloud-free moat between the eye walls resulted in a substantial drop in the default values of the DD number (160331Z July visible GMS imagery).

intensity estimates was 87 mb in 18 hours, resulting in an average decrease of 4.8 mb/hr. The explosive deepening was not anticipated, and 24-hour and 48-hour forecasts of Eve's intensity fell short by as much as 70 kt (36 m/sec) and 90 kt (46 m/sec) respectively during the two days prior to the event.

c. A discussion of Eve's DD time series

Infrared imagery is available hourly from the GMS satellite, and hourly DD numbers were calculated for all of the typhoons of 1996 (see Bart's (04W) summary for a detailed description of the DD algorithm installed on the JTWC's satellite image processing equipment). The discussion of the behavior of the time series of the DD numbers for Eve, and for some of the other typhoons of 1996, is intended to highlight certain aspects of the DD time series that may prove to have important research and/or warning implications.

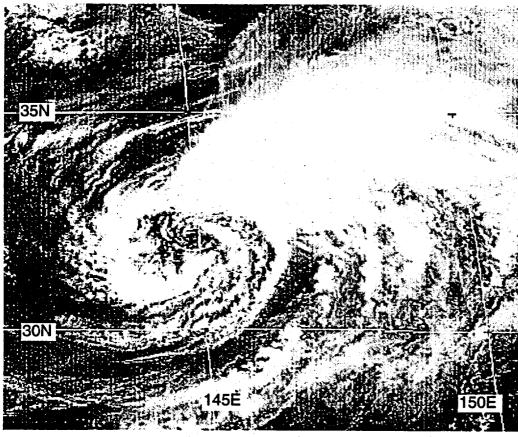


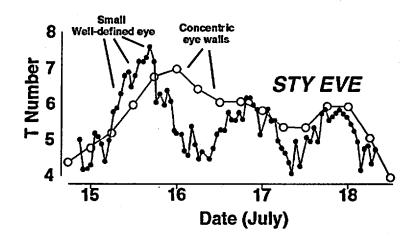
Figure 3-07-5
Exhibiting a Dvorak "shear" pattern type, Eve has regenerated and reached tropical-storm intensity after moving back over water to the east of Japan (220231Z July visible GMS imagery).

Eve is one of only a few cases during the past two years in which a strong diurnal cycle can be found in the time series of its DD numbers (Figure 3-04-6): higher DD numbers occur in the early morning hours (around 1800Z), and lower DD numbers occur in the late afternoon (around 0600Z). Although the DD number is based upon both the cloud-top temperature of the eye-wall cloud and the temperature within the eye, the apparently cyclical fluctuations in Eve's DD time series are linked more to major structural changes of the TC rather than fluctuations in the cloud-top temperatures of an otherwise stable cloud pattern. During the rise to the first DD peak during 15 July, Eve's eye evolved from a banding eye to a well-defined small eye. The fall of the DD numbers on 16 July is predominantly a manifestation of the formation of concentric eye walls. The default radius used to define the eye wall cloud-top temperature in the DD algorithm is 30 nm. When Eve

possessed concentric eye walls, this radius fell in the relatively cloud-free moat between the inner and outer wall clouds, and resulted in the period of low DD values after the first peak. The radius used to define the eye-wall cloud-top temperature is an adjustable parameter on the MIDDAS system, and when set to 10 nm it was able to measure Eve's intensity based on the cloud-top temperature of the inner eye wall. This resulted in DD numbers approximately one T number higher than those computed using the default radius when Eve possessed concentric eye walls.

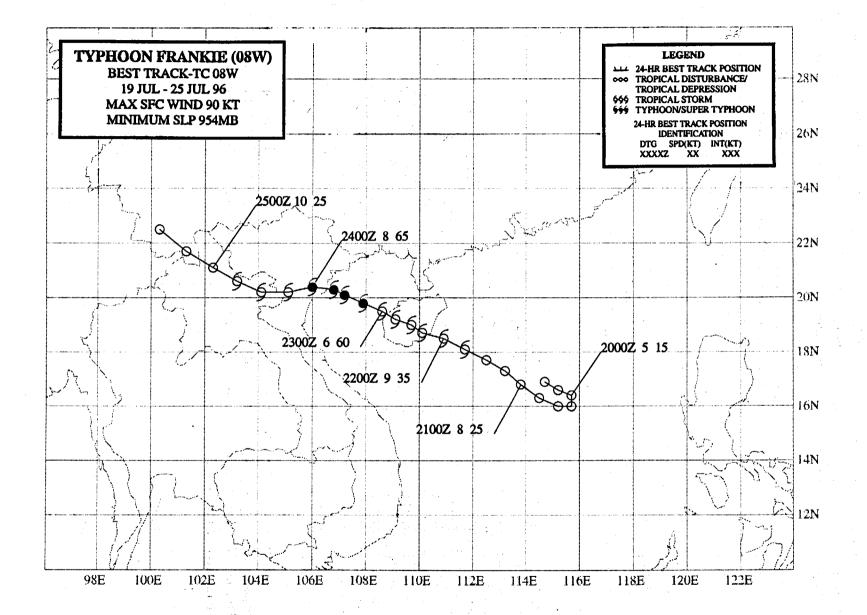
Thus, while diurnal fluctuations of the intensity estimate of a TC may be the result of the general observation that cloud-top temperatures of deep convection in the tropics tend to be coldest in the early morning, the diurnal fluctuations of Eve's DD time series can be linked to major structural changes of the eye which may have only coincidentally occurred at the diurnal time scale. A similar sharp rise of the DD time series to a peak of over T 7.0 followed by a drop to near T 5.0 (due to the formation of concentric wall clouds) occurred with Dale (36W). In the case of Dale (36W), the timing of the rise and fall of the DD time series was 180° out of phase with that of Eve and with the generally observed diurnal cycle of tropical cloud-top temperatures.

Figure 3-07-6 The time series of Eve's hourly DD numbers (small black dots connected by thin solid line). For comparison, the final best track intensity at six-hour intervals (converted to a T number) is superimposed (open circles connected by thin solid line).



IV. IMPACT

Strong winds and heavy rains affected the Japanese island of Kyushu, disrupting sea and air transport. Nine people were reported injured. The eye of Eve passed directly over the island of Yaku Jima (WMO 47836) in the northern Ryukyus where reports of wind gusts to 83 kt (43 m/sec) were received at the JTWC.



TYPHOON FRANKIE (08W)

I. HIGHLIGHTS

During late July, the monsoon trough became established across the northern half of the South China Sea and extended east-southeastward into Micronesia. Three TCs formed in this trough — Frankie, Gloria (09W), and Herb (10W). The westernmost of these three, Frankie originated from a monsoon depression in the South China Sea tracked to the west-northwest, and made landfall in northern Vietnam.

II. TRACK AND INTENSITY

During June and the first half of July, the monsoon trough was either very weak or absent from the tropics of the WNP. Easterly winds prevailed, and TC formation occurred at relatively high latitude (20°N) in association with disturbances in the TUTT. During the latter half of July, the first major penetration of the monsoon trough into Micronesia occurred. Inevitably, the monsoon cloud band consolidated into discrete areas of deep convection (in this case, three of them). The westernmost of the three areas of deep convection along the monsoon trough became a monsoon depression in the South China Sea (see the discussion section). It was first mentioned on the 180600Z July Significant Tropical Weather Advisory. A small well-defined LLCC (Figure 3-08-1) embedded within this monsoon depression became Frankie. A Tropical Cyclone Formation Alert was issued valid at 201100Z when deep convection continued to consolidate around the LLCC shown in Figure 3-08-1. Rapid development of a CDO pattern type with well-defined peripheral low-level cloud lines (Figure 3-08-2) prompted the JTWC to issue the first warning on Tropical Depression (TD) 08W, valid at 210000Z. During the early morning of 22 July, TD 08W formed a large CCC (Figure 3-08-3) prompting its upgrade to Tropical Storm Frankie on the warning valid at

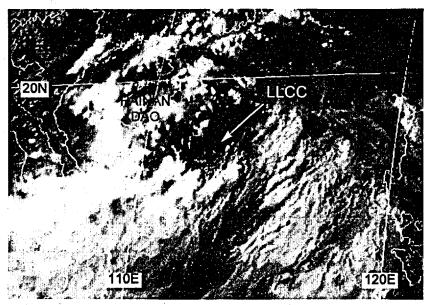


Figure 3-08-1 A small well-defined LLCC is present near the center of a monsoon depression. This LLCC became Frankie (210731Z July visible GMS imagery).

211800Z. After becoming a tropical storm, Frankie passed over the island of Hainan and continued to intensify. After clearing the west coast of Hainan, Frankie developed a ragged eye (Figure 3-08-4). Over the Gulf of Tonkin, the eye became better defined and Frankie was upgrade to a typhoon on the warning valid at 230600Z. The intensity peaked at 90 kt (46 m/sec) at 231200Z, and remained at that intensity until it crossed the coast of northern Vietnam at approximately 232200Z July. Thereafter, the system weakened, and the final warning was issued, valid at 240600Z.

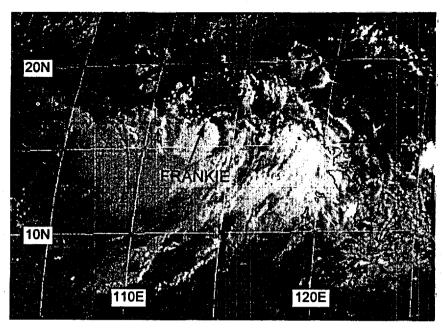


Figure 3-08-2 Deep convection becomes established over the LLCC shown in Figure 3-08-1 (202331Z July visible GMS imagery).



Figure 3-08-3 A large CCC erupts over the LLCC of Frankie. Coldest cloudtop temperature was -97°C (indicated by the arrow) (212224Z July enhanced infrared GMS imagery).

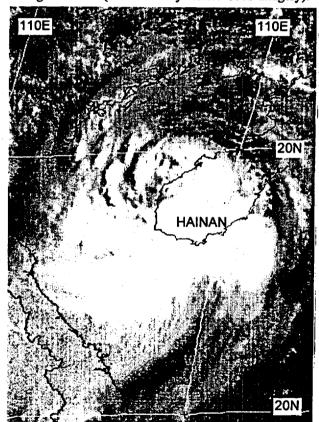


Figure 3-08-4 Frankie acquires a ragged eye as it clears the coast of Hainan island (230031Z July visible GMS imagery).

III. DISCUSSION

a. The transformation of a monsoon depression into a typhoon

Frankie originated from a monsoon depression — a common genesis pathway for TCs in the WNP (see Appendix A for a detailed description of monsoon depressions in the WNP). An unresolved question remains concerning the transition of a monsoon depression into a conventional TC: does the monsoon depression become the conventional TC, or does a conventional TC form within the circulation of the monsoon depression? In Frankie's case, it can be argued that the conventional TC (Frankie) formed within the preexisting circulation of the monsoon depression. The well-defined exposed LLCC (Figure 3-08-1) that became the focus of Frankie's deep convection was surrounded by an area of gales (Figure 3-08-5) before the core winds increased. When persistent deep convection appeared in the core of the monsoon depression, it quickly became a CDO-type conventional TC. Soon after the formation of Frankie's CDO, the peripheral cloudiness in the monsoon depression was suppressed and the areal extent and amount of

deep convection in the system became much smaller. TCs in the WNP that develop from monsoon-depressions tend to be large, and Frankie's small size is somewhat unusual. Perhaps the geomorphology of the Gulf of Tonkin contributed to the evolution of this monsoon depression into a small TC. Many TCs which move into the Gulf of Tonkin become smaller.

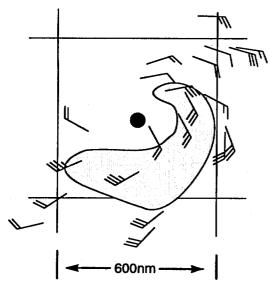


Figure 3-08-5 An area of gales existed in the monsoon depression before deep convection grew in its center (black dot) and the system became a conventional tropical cyclone. Wind reports are a center-relative composite of ship observations at 201200Z, 210000Z and 211200Z July.

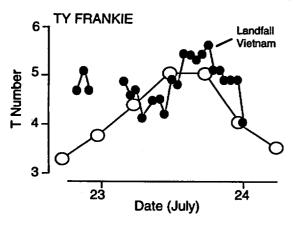


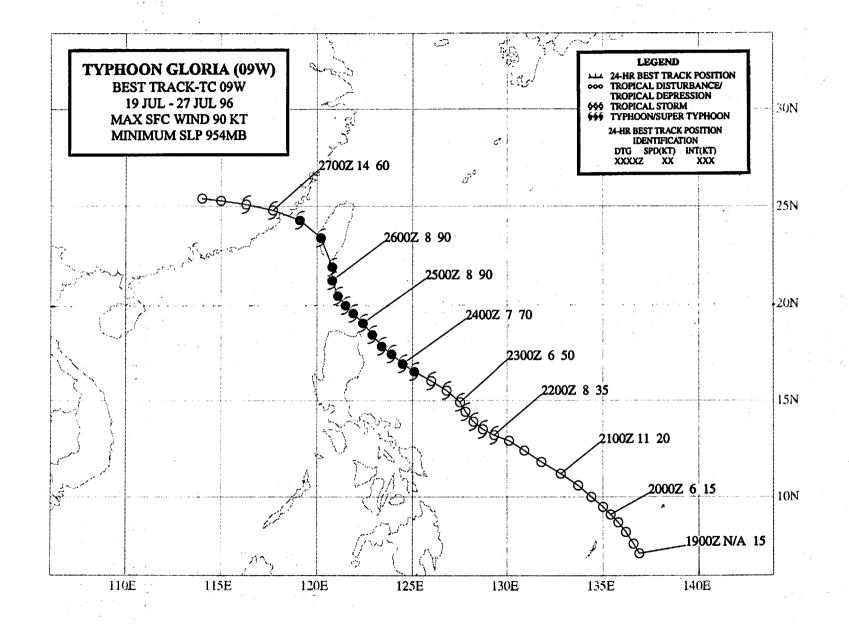
Figure 3-08-6 A time series of Frankie's intensity as it crossed the Gulf of Tonkin and made landfall in Vietnam. The hourly DD time series is indicated by black dots, and the six-hourly best-track intensity (converted to a T number) is indicated by the open circles.

b. Frankie's intensity time series

Upon entering the Gulf of Tonkin, Frankie acquired an eye and intensified from 50 kt (26 m/sec) to 90 kt (46 m/sec) in a period of 24 hours (Figure 3-08-6). The equivalent pressure drop of 33 mb in 24 hours was below the criteria for rapid deepening, defined as a decrease of 42 mb in 24 hours (Holliday and Thompson, 1979). The intensity increase did, however, qualify as "fast" in terms of its rise of more than 1.5 Dvorak T numbers in 24 hours. Dvorak classifies the rate of intensification of a TC as "slow". "normal", or "fast" if the 24-hour rise in its T-number estimate is 0.5, 1.0, and 1.5 respectively. Another aspect of Frankie's intensification over the Gulf of Tonkin concerns the timing of its peak. The best track indicates it reached its peak intensity approximately eight hours prior to landfall, while the DD numbers (Figure 3-08-6) continued to rise until the western eye-wall cloud made landfall. The discussion of the behavior of the time series of the DD numbers for Frankie, and for some of the other typhoons of 1996, is intended to highlight certain aspects of the DD time series that may prove to have important research and/or warning implications. Differences between the DD numbers and the best-track intensity are expected. and substantial disagreements are curiosities that lack ground-truth verification.

IV. IMPACT

Frankie caused extensive property damage and loss of life in the northern provinces of Vietnam. There were 104 people reported dead or missing, and 466 were reported injured. Total economic losses were estimated at over US \$200 million.



TYPHOON GLORIA (09W)

I. HIGHLIGHTS

Developing from a monsoon depression in the Philippine Sea, Gloria moved northwestward, became a typhoon, and affected Luzon, Taiwan, and eastern China. During the early phases of its development, Gloria formed a very large Central Cold Cover (CCC) with a near-record cloud-top temperature of -100°C.

II. TRACK AND INTENSITY

During the latter half of July, extensive amounts of deep convection formed in an east-west band extending across the WNP from the coast of Southeast Asia to the Marshall Islands. By 21 July, this cloud band had consolidated into three distinct cloud clusters (see Figure 3-10-1 in Herb's (10W) summary), all of which became named tropical cyclones — from west to east: Frankie (08W), Gloria, and Herb (10W). The tropical disturbance which became Gloria was first mentioned on the 170600Z July Significant Tropical Weather Advisory when synoptic data from Koror (WMO 91408) indicated the presence of a weak cyclonic circulation associated with a region of enhanced deep convection along the monsoon trough. Over the course of the next few days this disturbance moved slowly westward without much sign of increased organization in the deep convection or the surface wind field.

Early on 21 July, convection in the pre-Gloria disturbance became more organized and the first of two Tropical Cyclone Formation Alerts (TCFA) was issued valid at 201830Z. The areal extent of deep convection in this disturbance increased markedly, and the system acquired the structure of a monsoon depression. Although the cloud system appeared to be well organized, synoptic data still indicated that the winds were weak, and most of the deep convection had not yet consolidated near the low-level circulation center (LLCC). Thus, a second TCFA was issued valid at 211830Z, containing a caution stating deep convection had begun to develop near the LLCC (Figure 3-09-1), and formation of a significant tropical cyclone was anticipated within 6 to 12 hours. Indeed, when synoptic reports were received which indicated the wind speed had reached 30 kt (15 m/sec) in the broad circulation, the first warning on Tropical Depression 09W was issued valid at 220000Z. Steering flow was dominated by a strong subtropical ridge to its north, and Gloria was forecast to move on a steady west-northwest track towards Luzon.

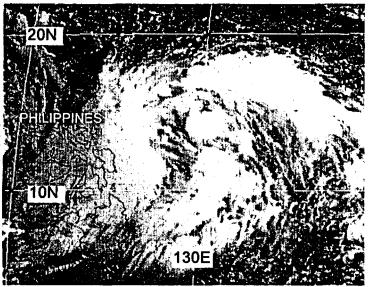


Figure 3-09-1 The mesoscale convective systems within the pre-Gloria monsoon depression show signs of increased organization and consolidation toward the LLCC, prompting the first warning (212224Z July visible GMS imagery).

Based upon synoptic reports of gales within the large circulation, TD 09W was upgraded to Tropical Storm Gloria on the warning valid at 221200Z. During the night, following its upgrade to tropical-storm intensity, and subsequent increase to 55 kt (28 m/sec), Gloria underwent a profound structural change: a very large Central Cold Cover (CCC) formed (see the discussion section). This CCC persisted from the late evening of 23 July to the morning of 24 July. As the CCC began to dissipate, Gloria became a typhoon. By the afternoon of 24 July, the cirrus debris of the CCC had largely cleared away revealing that Gloria had acquired a visible eye.

Tracking on a more northwestward course than forecast, Gloria brushed by Luzon and entered the Luzon Strait. It is here, during the afternoon of 26 August that Gloria made an abrupt jog to the north to make landfall on the southern tip of Taiwan. The typhoon then made a quick jump to the western coast of Taiwan, where it then turned to the west, crossed the Taiwan Strait and went inland in southeastern China. The peak intensity of 90 kt (46 m/sec) was maintained from 241200Z to 260600Z as Gloria moved across the Luzon Strait and made landfall in Taiwan. After landfall in Taiwan, its intensity dropped to the typhoon threshold, and having little time to recover during its passage across the Taiwan Strait, it entered mainland China as a minimal typhoon and quickly dissipated over land. The final warning was issued at 270600Z.

III. DISCUSSION

a. An unusually large Central Cold Cover

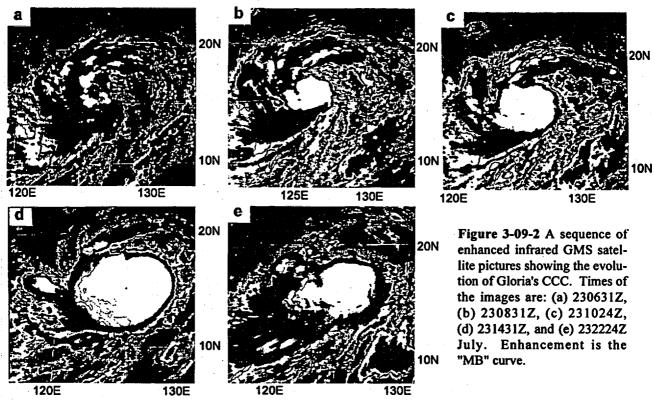
Dvorak (1984) noted that the use of enhanced IR imagery required the introduction of a new concept — the central cold cover (CCC) — in order to deal with the occurrence of a sudden spreading of cold clouds over the central features of a TC. When a CCC persists, it signals an interruption in the development of the TC. Specific details of the CCC pattern are found in Dvorak (1984):

"The CCC pattern is defined when a more or less round, cold overcast mass of clouds covers the storm center or comma head obscuring the expected signs of pattern evolution. The outer curved bands and lines usually weaken with the onset of CCC. When using VIS pictures, substitute the word 'dense' for 'cold'. It is only rarely that the CCC pattern is used with VIS pictures since the CDO [central dense overcast] or curved lines are usually visible through the thin cirrus clouds. When the CCC persists . . . , development has been arrested until signs of development or weakening once again appear in the cloud features. Care should be exercised under the following conditions:

- "1) Do not confuse a CCC pattern with a very cold comma pattern. A very cold (usually white [i.e., a gray-shade enhancement on the BD curve that is indicative of temperatures between -70 to -75°C]) pattern is indicated by a very cold (very smooth texture) comma tail and head with some indication of a wedge in between. Curved cirrus lines or boundaries usually appear around the [very] cold [comma] pattern and not around the CCC pattern. The very cold [comma] pattern for T-numbers of T3 or less warrant an additional 1/2 number in intensity estimate and often indicates rapid growth.
- "2) Do not assume weakening in a CCC pattern when the comma tail begins to decrease in size. It is common to observe the tail decreasing in size at the onset of the CCC. Also, the CCC often warms as the eye of the T4 pattern begins to be carved out by a warm incursion into the side of the cold overcast. This signals the resumption of pattern evolution (intensification) even though some warming is evident."

In the WNP, the CCC pattern is observed every year in the developmental process of several of the named TCs. One major difference between the CCC pattern observed in the WNP versus the North Atlantic (where Dvorak obtained most of the data for the development of his techniques) is that the cloud-top temperature of the CCC tends to be at least 10°C to 15°C colder in the WNP. Another difference between the CCC patterns observed in the WNP versus those observed in the Atlantic is the very large size of some of the CCC patterns observed in the WNP.

Prior to the formation of its CCC, Gloria had been developing as a monsoon depression. During the evening hours of 23 July, a cluster of small cold-topped MCSs began to grow near the estimated center position of Gloria. During a six-hour period, this cluster of MCSs mushroomed into an enormous CCC (Figure 3-09-2a-e). By local midnight, the average diameter of the area within which the cloud-top temperature was at or below -70°C was approximately 700 km (Figure 3-09-3). Roughly half of this area was colder than -90°C. The coldest IR pixel, with an equivalent black-body temperature of -100°C, was located near the geometric center of the CCC. This is an extremely cold cloud-top temperature which is rarely seen. It is only 2°C shy of the record cold cloud-top temperature of -102°C reported by Ebert and Holland (1992) in the deep convection associated with a TC near Australia.



By the early daylight hours of 24 July, the periphery of the CCC began to warm on IR imagery, and a new smaller CCC mushroomed into the preexisting cold cirrus canopy (Figure 3-09-4). As the day progressed, the underlying structure of Gloria gradually emerged in VIS imagery as the supporting convection of the CCC ended, and the large cirrus canopy of the CCC thinned. By mid-afternoon, the cold cirrus of the CCC became nearly transparent, and the eye, wall cloud, and peripheral convective cloud bands of the intensifying Gloria were then plainly seen (Figure 3-09-5).

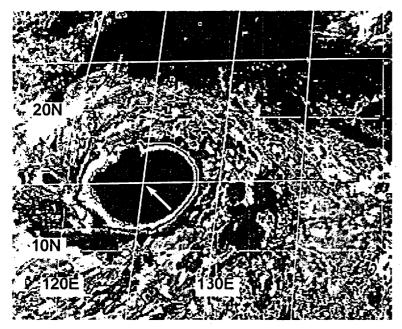
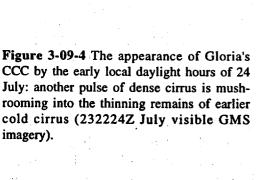


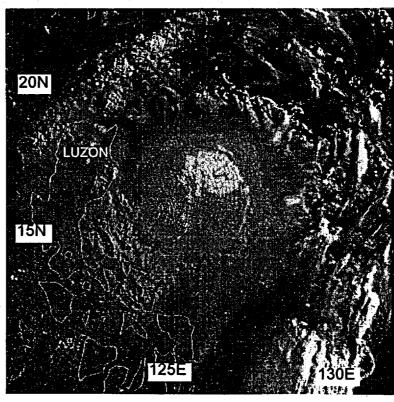
Figure 3-09-3 Gloria's CCC reaches its maximum areal extent, and registers its coldest temperatures. The location of the coldest temperature of -100°C is indicated by the arrow. Enhancement is the basic Dvorak, or "BD", curve applied to the 231431Z July infrared GMS imagery.

In the 24-hour period encompassing the full evolution of Gloria's CCC, the estimated intensity increased from 55 kt to 75 kt; hardly a remarkable change considering the extreme changes in the cloud pattern. This is consistent with Dvorak's findings that the appearance of a CCC signals arrested (or at least slowed) development which is renewed as the eye pattern of the T4 (minimal typhoon intensity) emerges beneath the thinning cirrus. Additional observations made during the occurrence of the CCC pattern in WNP TCs include the following:

1) the CCC usually begins to form at local sunset (this is at some variance with observations by Black and collaborators (e.g., Black, 1983; Black, et al., 1986; Black and Marks, 1987) who



imagery).



show that major cold convective eruptions in TCs tend to be initiated in the early morning);

- 2) the CCC reaches its greatest size and coldest temperature between local midnight and predawn; and,
- 3) the CCC pattern is most commonly observed to occur in weaker TCs that are at intensities of between T3 to T4 (45 65 kt) (this is consistent with observations of the aforementioned Black and collaborators; it is not consistent with guidance in Dvorak's 1984 report wherein it is stated that the CCC could occur at any stage of development of the TC and last for several hours to several days).

b. The influence of Taiwan on the motion of tropical cyclones

As Gloria was moving slowly to the northwest in the Luzon Strait, it made an abrupt turn to the north, and made landfall on the extreme southern tip of Taiwan. It then made an abrupt jump to the west coast of Taiwan before resuming a westward track toward mainland China. It is offered as a hypothesis that this abrupt meander in Gloria's track was induced by the island of Taiwan. Research by the Taiwan Central Weather Bureau (CWB) (1982) has demonstrated that the island of Taiwan can significantly alter the tracks of typhoons that approach it. The effects differ depending upon the angle of approach. The track changes noted during Gloria's approach to Taiwan are consistent with the track changes noted by the CWB which occur when a typhoon approaches Taiwan from the south or southeast.

IV. IMPACT

In the Philippines, Gloria was reported to have killed at least 20 people and caused nearly US \$40 million in property damage. Hardest hit were the northeastern provinces of Luzon, where the eye of Gloria approached to within 60 nm (110 km) of the northeastern tip of the island. Gloria

also passed to within 60 nm (110 km) of some of the smaller islands in the Luzon Strait where, although there were reports of typhoon force winds, the JTWC received no reports of any damage or injuries. On Taiwan, three people were reported killed: a child by a falling tree, an adult as he was blown from his motorcycle into a creek, and another adult as he fell from a roof. Rock slides disrupted traffic along Taiwan's east coast, and heavy rains flooded fields and caused several rivers to overflow their banks.

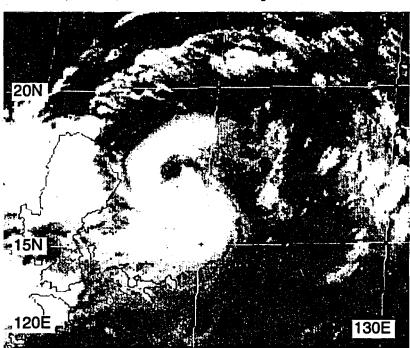
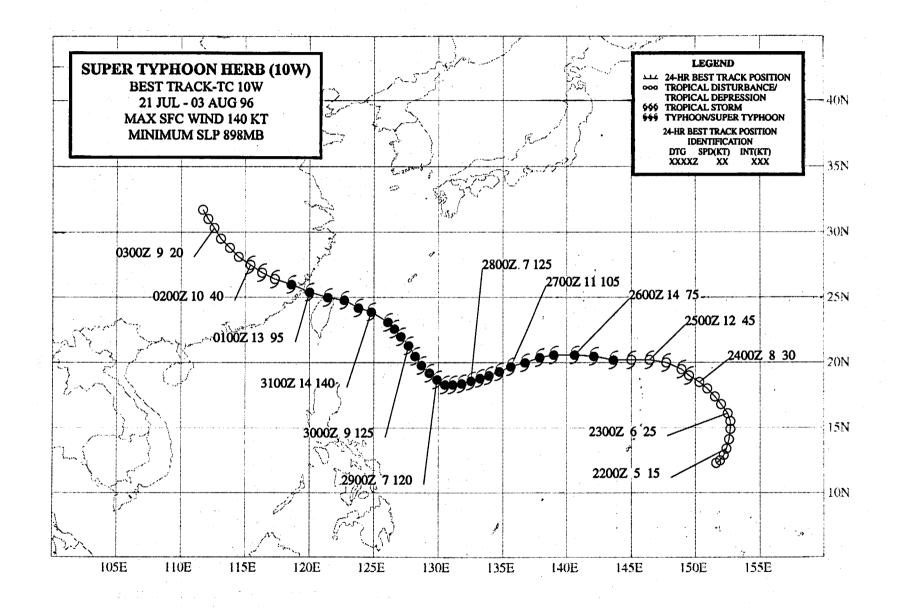


Figure 3-09-5 The eye, wall cloud, and peripheral rainbands of Gloria are plainly visible after the cirrus overcast of the CCC cleared away (240531Z visible GMS imagery).



SUPER TYPHOON HERB (10W)

I. HIGHLIGHTS

When Herb formed, it became the easternmost of three tropical cyclones simultaneously active along the monsoon trough — the other two were Frankie (08W) and Gloria (09W). Herb's mode of formation was somewhat unusual: the cloud cluster from which it developed became organized into a "fishhook" cloud pattern. While moving generally westward toward China, Herb peaked twice in intensity. As the tropical cyclone neared its second peak intensity, it possessed a large eye. In addition, Herb was also a very large tropical cyclone; the largest tropical cyclone in terms of the mean Radius of Outermost Closed Isobar (ROCI) in the WNP during 1996. Herb made landfall in the southern Ryukyu Islands, Taiwan, and mainland China. Significant property damage and loss of life were attributed to Herb in these areas. On Taiwan, a new NEXRAD WSR 88D took a direct hit from Herb, and was severely damaged.

II. TRACK AND INTENSITY

During the latter half of July, extensive amounts of deep convection formed in an east-west band extending across the WNP from the coast of Southeast Asia to the Marshall Islands. By 21 July, this cloud band had consolidated into three distinct cloud clusters (Figure 3-10-1), all of which became named tropical cyclones — from west to east: Frankie (08W), Gloria (09W), and Herb.

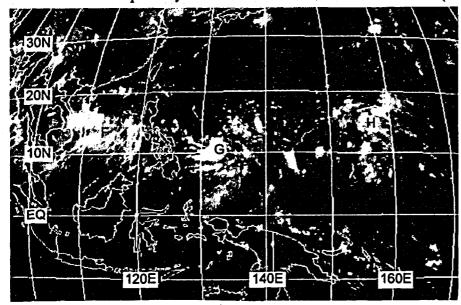


Figure 3-10-1 The cloudiness associated with the monsoon trough consolidates into three distinct cloud clusters that will soon become Frankie (08W), Gloria (09W), and Herb (201831Z July Infrared GMS imagery).

Based upon 24-hours of persistent deep convection, and synoptic data indicating the presence of an associated weak low-level cyclone beneath upper-level anticyclonic flow, the tropical disturbance that became Herb was first mentioned on the 210600Z July Significant Tropical Weather Advisory. Convection in this disturbance remained poorly organized until the morning of 23 July, when deep convection consolidated within a smaller area, and microwave imager data and visible satellite imagery indicated improved

organization of the low-level circulation center (LLCC). This prompted the JTWC to issue a TCFA valid at 230000Z. Continued improvements in the organization of low-level cloud lines accompanying a persistent area of deep convection near the LLCC led to the first warning on Tropical Depression (TD) 10W valid at 230600Z.

Based upon satellite intensity estimates, TD 10W was upgraded to Tropical Storm Herb on the warning valid at 240600Z. After becoming a tropical storm, Herb's central deep convection began to detach from the peripheral monsoon cloudiness to form a fishhook pattern (Figure 3-10-2).

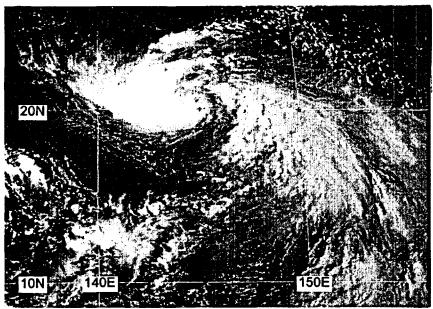


Figure 3-10-2 Herb's central deep convection begins to detach from the end of a fishhook shaped cloud pattern (250631Z July visible GMS imagery).

Figure 3-10-3 Herb nears its first of two intensity maxima: (a) 270331Z July visible GMS imagery and (b) 270331Z July enhanced infrared GMS imagery.

As the cloud system center moved to the head of the fishhook cloud pattern, Herb's motion became more westward. On a westward heading, Herb began to intensify and grow in size. Herb became a typhoon at 251200Z, and 48 hours later it reached 125 kt (64 m/sec) (Figure 3-10-3a,b); the first of two intensity maxima. At this time, Herb was moving in an unusual west-southwestward direction. This unusual motion may have been the result of an indirect interaction with Typhoon Gloria (09W) (the various types of direct and indirect interactions between two tropical cyclones

are discussed in detail by Carr and Elsberry (1994)).

On 29 July, Herb began to weaken with its intensity falling to 115 kt (59 m/sec) at 290600Z. While the typhoon weakened, the system made a gradual track change from a west-southwestward heading during 28 July to a northwestward heading during 29 July. Although weakened slightly, Herb had become a very large tropical cyclone with a mean ROCI of approximately 8.5° of great-circle arc (Figure 3-10-4). Early on 30 July, Herb began to intensify once again, reaching a peak of 140 kt (72 m/sec) at

301800Z (Figure 3-10-5). After reaching its peak intensity, Herb took a more westward course which brought it ashore on the northeast tip of Taiwan at approximately 311600Z with a landfall intensity of 130 kt (67 m/sec). Passing over Taiwan, Herb lost its eye, but then regained a ragged eye during its short passage across the Taiwan Strait. It quickly lost its eye over land in China. The final warning was issued valid at 011200Z August as the system moved farther inland and dissipated.

III: DISCUSSION

a. Unusual genesis

While Herb was forming in the monsoon trough, it followed an unusual developmental pathway: the deep convection associated with Herb's LLCC moved on a backwards "C" shaped trajecto-

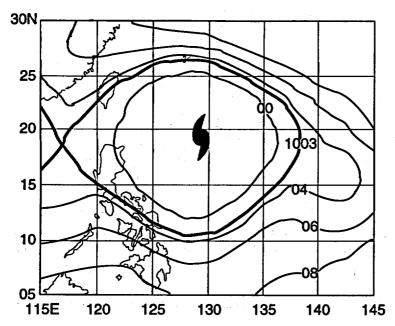


Figure 3-10-4 Herb became a very large tropical cyclone, the largest of 1996 in the WNP. As a measure of its size, the average radius of the outermost closed isobar is over 8.5° of great circle arc at 290000Z July. (290000Z July NOGAPS SLP analysis).

Z5N
TAIWAN
20N
125E
130E

Figure 3-10-5 Herb at peak intensity of 140 kt (72 m/sec) (302224Z July visible GMS imagery).

ry and gradually detached from the peripheral monsoon cloudiness to form a fishhook pattern (Figure 3-10-2). When the monsoon trough becomes organized as a monsoon gyre (Lander 1994) (see Appendix A), the large-scale monsoon cloud band often becomes organized into a large fishhook cloud pattern. One, or more, tropical cyclones may traverse the eastern periphery of the monsoon gyre (in a cyclonic orbit of the gyre) and emerge from the end of the fishhook. Although smaller in scale than the monsoon gyres cited by Lander (1994), the process of organization of the monsoon cloud pattern into a fishhook, and the backwards "C" motion of Herb as the fishhook evolved, are consistent with the cloud evolution and behavior of tropical cyclones associated with larger monsoon gyres.

b. Three periods of intensification

The time series of the DD numbers obtained for Herb (Figure 3-10-6) indicate three maxima: one maximum at approximately 270000Z, a second at approximately 281800Z, and a third sustained maximum during 30 July. The first maximum indicated by the DD algorithm occurred a little bit ahead of the first maximum in the final best track intensity. The best track intensity does not reflect the fall and rise of the DD time series to its second maximum. One reason for this, is that as the T-number falls, the Dvorak

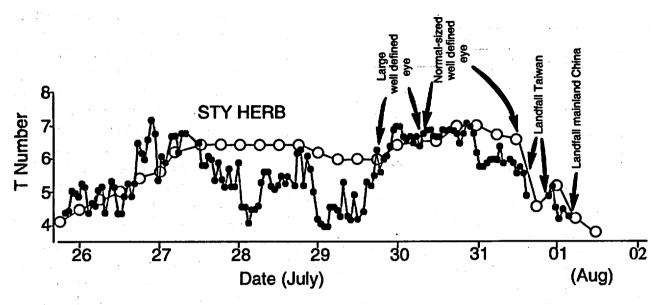


Figure 3-10-6 The time series of Herb's Digital Dvorak "DD" numbers (small dark circles) with the final best track intensity superimposed (large open circles).

technique requires that the current intensity be held one-half to one number higher than the T-number for at least 12 hours. For the most part, this is true of a comparison of Herb's DD time series with its final best track intensities (Figure 3-10-6). The second drop of intensity indicated on the DD time series was reflected by a slight drop in the warning and best track intensity before both rose once again to the peak that occurred on 30 July. Note that the DD time series contains some rather large fluctuations that do not appear in the final best track intensity time series. It is not known to what extent the fluctuations in the DD time series may represent actual short term changes in the intensity of tropical cyclones (see Bart's (04W) summary for a discussion of the DD algorithm).

c. Largest tropical cyclone of 1996

Super Typhoon Herb was the largest tropical cyclone of 1996. Using the mean ROCI as a measure of Herb's size, the system surpassed the threshold of the "very large" size category used by the JTWC (see Appendix A). At its largest, the mean ROCI of Herb was about 8.5° of great-circle arc (GCA) (Figure 3-10-4).

Tropical cyclone size is a very difficult parameter to objectively measure. Merrill (1984) classified a tropical cyclone as "small" if the mean ROCI was three degrees (180 nm, 335 km) GCA, or smaller; as "medium" if the mean ROCI was between three to five degrees GCA (180 nm (335 km) to 300 nm (555 km)), and as "large" if the mean ROCI was greater than five degrees GCA (greater than 300 nm). The Japan Meteorological Agency (JMA) recognizes two additional size categories — "very small" and "ultra large" — that mesh neatly with Merrill's scheme. The definitions of size used herein (see Appendix A) have been adapted by a mesh of the JMA size categories with those of Merrill.

d. Eyewall mesocyclonic vortices as seen by Taiwan's NEXRAD

Eyewall mesocyclonic vortices (EMs) were first detected and documented in airborne Doppler radar data by Marks and Houze (1984) and also with aircraft inertial navigation equipment as noted by Black and Marks (1991). Stewart and Lyons (1996) identified EMs with the Guam

NEXRAD in association with the passage of Super Typhoon Ed (1993). Until the implementation of the NEXRAD radar network in the United States during the early 1990s, only chance encounters with EMs have occurred during reconnaissance aircraft penetrations. However, now that Doppler velocity data are available, strong mesocyclones associated with TC outer convective bands and eyewall convection are frequently detected.

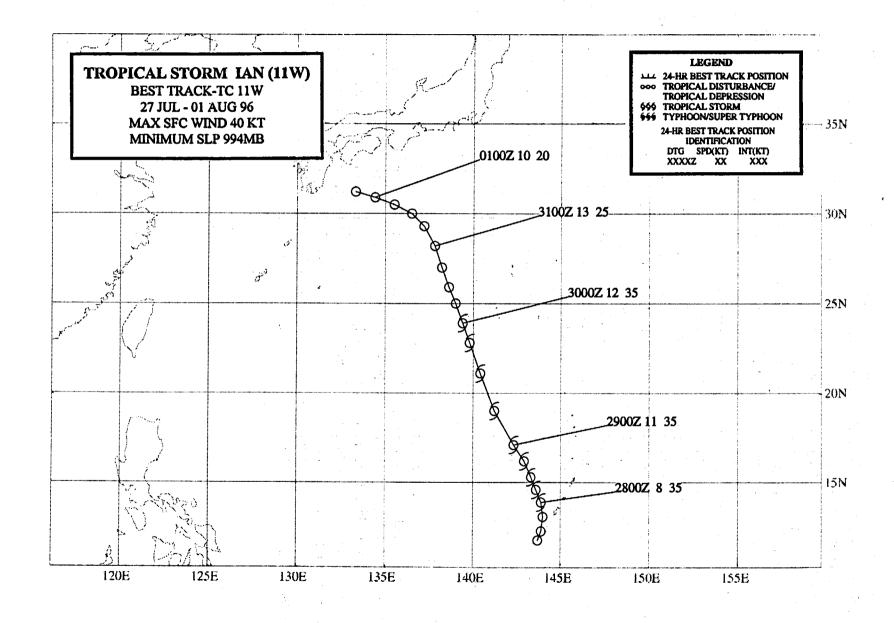
Stewart et al. (1997) used NEXRAD data to show that EMs in the wall clouds of TC eyes may be a mechanism for TC intensification and for extreme wind bursts in TCs as noted with Hurricane Andrew damage (Wakimoto and Black 1993). In three cases (including Herb), the TC underwent a period of rapid intensification during which time several vertically deep, EMs formed prior to the occurrence of rapid intensification and persisted for several hours while rapid deepening was occurring. Comments from Stewart et al. (1996) include:

"Approximately three hours prior to landfall in Taiwan, satellite imagery indicated Herb had weakened... In contrast, the [Taiwan NEXRAD] indicated that Herb was actually intensifying... As early as 310656Z July, [the NEXRAD] indicated intense EMs had begun to develop and this trend continued until the last available data at 311350Z [when the data record ended because of damage to the radar by high wind.]... Although the [Taiwan NEXRAD] detected several EMs (as many as 6 EMs occurred simultaneously in the eyewall), one particular EM became quite intense and persisted for more than 1.5 hours just prior to Herb's landfall... This particular EM peaked at 311314Z with a rotational shear of 0.075/sec which is more than triple the [NEXRAD] criteria for a Tornadic Vortex Signature..."

Based on observations of EMs in TCs (including Herb), Stewart et al. (1997) conclude that the EMs appear to have a positive feedback on TC intensification.

IV. IMPACT

In addition to the destruction of Taiwan's NEXRAD, Herb caused extensive damage to property and agriculture in Taiwan and China. At least 51 lives were lost and 22 missing in Taiwan. Twenty-four of these lives were lost in the city of Nantou, 120 miles south of Taipei, due to rock-slides and flooding. Daily rain totals of nearly 40 inches (1000 mm) were reported over the central mountain range. An estimated US \$5 billion dollars of damage to crops, roads and power equipment was reported in Taiwan. In China, rains from Herb contributed to flooding that killed upwards of 250 people. In Fujian Province, 950 miles south of Beijing, at least 233 people were reported killed and 284 missing when flooding destroyed 70,000 homes.



TROPICAL STORM IAN (11W)

I. HIGHLIGHTS

Ian formed at the end of the monsoon trough and then moved on a north-northwestward track while embedded within the peripheral southerly flow on the eastern side of the very large Super Typhoon Herb (10W). The initial warnings on Ian were based primarily on synoptic reports from the islands of Guam and Saipan because the circulation was poorly organized on satellite imagery.

II. TRACK AND INTENSITY

During the final week of July, Super Typhoon Herb (10W) grew in size and came to dominate much of the flow of the WNP. On 27 July, a large area of deep convection became established in the monsoon flow to the south and east of Herb (Figure 3-11-1). The possibility of tropical cyclogenesis occurring in association with this area of deep convection was first mentioned on the 271800Z Significant Tropical Weather Advisory. Comments on this advisory included:

"... An area of convection is located [southeast of Guam]... within the monsoon trough. Sounding data from Guam indicates falling heights throughout the lower troposphere. Additionally, northerly winds at Guam suggest a circulation center southeast of the island. As Typhoon Herb moves westward, this region becomes an increasingly favorable genesis area..."

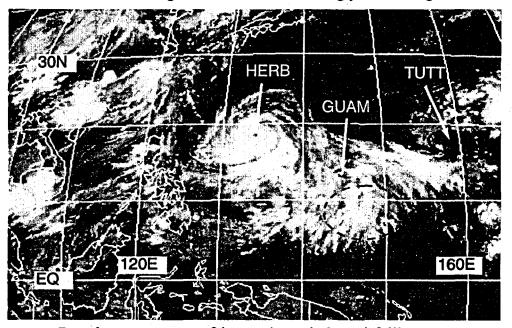


Figure 3-11-1 A large ensemble of mesoscale convective systems develops in monsoon flow to the southeast of Herb (dashed circular area) (271331Z July infrared GMS imagery).

Based upon reports of increasing winds and falling pressures on Guam and Saipan, a Tropical Cyclone Formation Alert was issued valid at 280430Z. The circulation center was then estimated to have been approximately 50 nm (90 km) to the west of Guam, and drifting slowly northward. Later that day, two ships moored at Saipan reported to the JTWC that they were experiencing gales and had to put to sea. Based upon these ship reports, and from high winds (20 to 30 kt) and low pressure (1003 mb) experienced on Guam and Saipan, the first warning on Tropical Depression (TD) 11W was released valid at 281200Z. When an area of persistent deep convection became established near the estimated center location, TD 11W was upgraded to Tropical Storm Ian on the warning valid at 290000Z. In post analysis, based upon data recorded in the logs of the

aforementioned ships which had to depart Saipan, and upon indications on microwave imagery (Figure 3-11-2) that the organization of the deep convection was better than indicated on conventional visible (Figure 3-11-3) and infrared satellite imagery, TD 11W was increased to a tropical storm at 280000Z.

On 29 July, a third TC — TD 12W formed within a TUTT cell to the northeast of Ian (see Joy's (12W) summary and figure 3-11-1) to create a reverse-oriented monsoon trough that stretched northeastward from Herb (10W). Embedded in this trough, and also embedded in the large circulation of Herb (10W), Ian moved northward, as anticipated. Strong upper-level northwesterly winds, which were part of Herb's extensive outflow, exerted shear on Ian, and the system failed to mature. Instead, the low-level circulation center (LLCC) became displaced to the north of Ian's deep convection, and the system was downgraded to a tropical depression on the warning valid at 300600Z. On 31 July, deep convection was completely sheared away from Ian's LLCC, and the final warning was issued valid at 310600Z as the exposed LLCC slowly dissipated over water to the south of Japan.

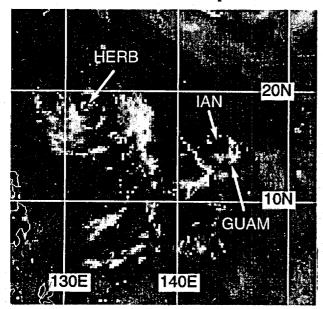
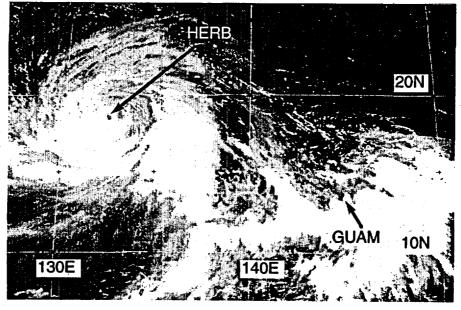


Figure 3-11-2 Deep convection associated with Ian is organized into cyclonically-curved bands (280914Z July 85 GHz microwave DMSP imagery).

Figure 3-11-3 Although the deep convection appears to be poorly organized, a low pressure area associated with over-water gales has developed near Guam and Saipan. In post analysis, Ian became a tropical storm at this time (272331Z July visible GMS imagery).



III. DISCUSSION

a. Unusual structure

As Ian moved northward in a cyclonically-curved track around the eastern periphery of the larger circulation of Herb (10W), it was often difficult to establish whether it was an independent cyclonic circulation, vice a cusp or a wave. Synoptic data indicated for most of its life, Ian took the form of a cusp, with a region of gales on its eastern side and a zero velocity singularity at the center (or at most, a very small region of northerly winds on its western side) (Figure 3-11-4). When Ian passed Guam and Saipan, it was at first thought the high winds were associated with a surge (or squall line) in the monsoon. The drop of pressure to 1003 mb at its closest point of approach, the day-long duration of high wind, and a subsequent 24-hour pressure rise of 8 mb in 24 hours at Guam, however, were more consistent with the passage of a tropical cyclone.

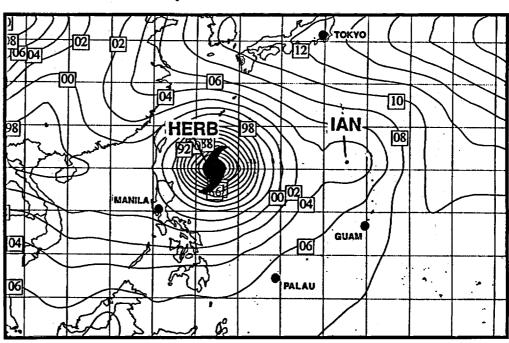
b. Ian as a "satellite" of Herb (10W)

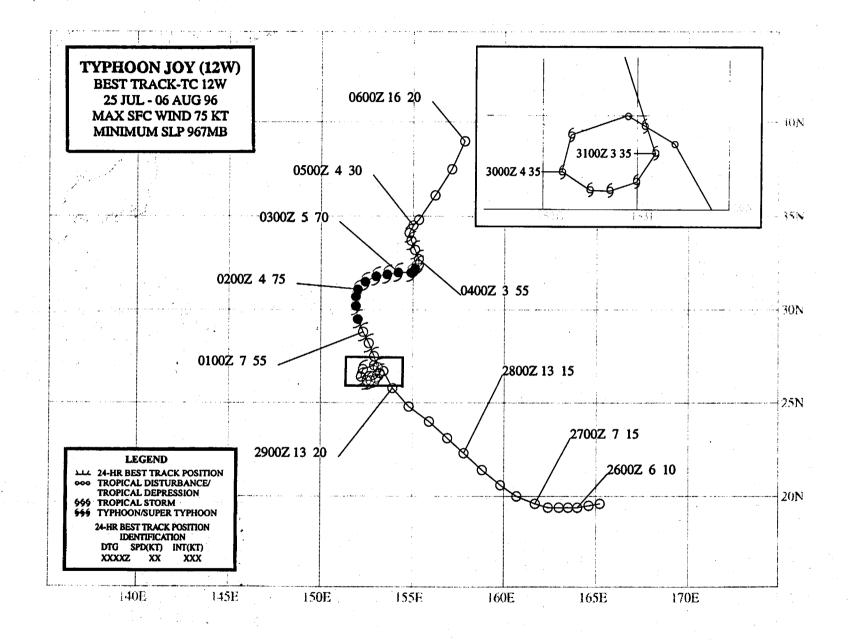
Occasionally, small TCs are observed to develop in the peripheral flow of very large TCs in the WNP. These small TCs tend to be weak, have short life spans, and are advected around the larger TC. These small TCs which form and orbit in the peripheral flow of very large TCs will herein be called "satellite" TCs, based upon the astronomical analogy of a small object (i.e., a satellite) in orbit of a much larger object. Very large TCs in recent years which have had smaller "satellite" TCs in their peripheral circulation include Abby (1983) which had two "satellites" (Ben and Carmen), and Hal (1988) which also had two "satellites" (Jeff and Irma). Ian was a "satellite" TC of the very large Herb (10W), and was closely analogous with respect to its cloud signature and relative position to Hal's "satellite", Irma (1988).

IV. IMPACT

Much of the northern half of Saipan lost power when high winds associated with Ian caused power lines to short out against tree branches. Some similar spot power outages occurred on Guam. Also on Saipan, some ships at anchor were forced to put to sea. No other reports of significant damage or injuries attributable to Ian were received by the JTWC.

Figure 3-11-4
Ian, which is embedded within the strong southerly flow on the eastern side of Herb, is difficult to "close-off" (290000Z July NOGAPS sea-level pressure analysis).





TYPHOON JOY (12W)

I. HIGHLIGHTS

Joy formed at a relatively high latitude in direct association with a TUTT cell, and did not become a typhoon until it had moved to nearly 30°N. Prevented from recurving by a blocking high, the system moved slowly on a meandering north-oriented track.

II. TRACK AND INTENSITY

During the final week of July, a monsoon trough became established across the WNP, and three tropical cyclones formed simultaneously in this trough — Frankie (08W), Gloria (09W), and Herb (10W). Several days later, Ian (11W) and Kirk (13W) also formed at the eastern end of this monsoon trough. During the time this activity was occurring in the monsoon trough, a TUTT cell (that was first detected near the international date line), was moving slowly westward along 20°N. The tropical disturbance which became Joy originated directly from deep convection associated with this TUTT cell (see the discussion section for more details). On 27 July, deep convection associated with this TUTT cell increased, cirrus outflow became organized into a well-defined anticyclonic pattern, and visible satellite imagery indicated that a low-level circulation had formed, which led to its inclusion on the 270600Z July Significant Tropical Weather Advisory. Comments on this advisory included:

"... An area of convection is located near 21N 160E. Visible satellite imagery indicates the presence of a low-level cyclonic circulation beneath well-defined anticyclonic flow aloft. Water vapor imagery also indicates that a [TUTT] cell is located to the south of the disturbance..."

The TUTT cell continued its westward motion for the next two days, and the convection located to its north remained poorly organized until 29 July when a small area of deep convection persisted near the estimated low-level circulation center. The first warning on Tropical Depression (TD) 12W was issued valid at 290600Z based on a satellite intensity estimate of 25 kt (13 m/sec).

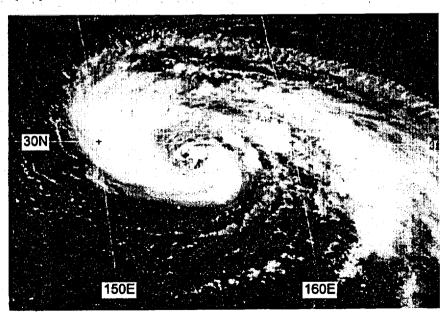


Figure 3-12-1 Joy's primary band of deep convection coils into a banding-type eye (010331Z August visible GMS imagery).

Upgrade of TD 12W to Tropical Storm Joy occurred on the warning valid at 300000Z, based upon a satellite intensity estimate of 35 kt (18 m/sec).

Between 29 and 30 July, Joy remained nearly stationary in weak steering before intensifying as it began moving slowly toward the north-northwest on 31 July. During the daylight hours of 01 August, Joy became well-organized, and its primary band of deep convection became tightly coiled to form a banding-type eye (Figure 3-12-1). This prompted the JTWC to upgrade Joy to a typhoon on the warning valid at 010600Z September.

Meandering slowly northward, Joy reached its peak intensity of 75 kt (39 m/sec) at 011800Z (Figure 3-12-2).

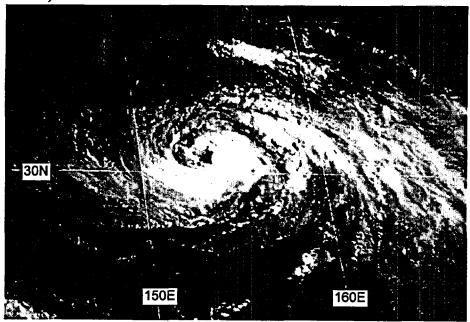


Figure 3-12-2 Joy at its peak intensity of 75 kt (39 m/sec) (012131Z August visible GMS imagery).

Continuing its slow northward drift, Joy began to shear on 04 August. On 05 August, Joy still had some deep convection located to the east of its exposed LLCC. but it had begun to accelerate toward the northnortheast as it interacted with a slow moving north-south oriented frontal cloud band. Expecting Joy to merge with the frontal cloud band and become extratropical, the JTWC issued the final warning valid at 050600Z.

III. DISCUSSION

Tropical cyclogenesis induced by a TUTT cell

A persistent feature of the upper-tropospheric flow over the tropics of the WNP and North Atlantic oceans during the summer is the tropical upper-tropospheric trough (TUTT) (Sadler, 1975). In the mean, the axis of the TUTT overlies low-level easterly trade wind flow approximately midway between the axis of the subtropical ridge and the axis of the monsoon trough.

In synoptic analyses, the TUTT is commonly observed to consist of a chain of westward moving synoptic-scale cyclonic vortices called "TUTT cells" in the WNP ("upper cold lows" in the Atlantic). The typical distribution of clouds associated with a TUTT cell features a relatively small region of isolated cumulonimbi (CB) or small mesoscale convective systems (MCS) within (or very near) its core. Sometimes extensive multi-layered clouds with embedded CB and MCSs are found to its south and east. The cloudiness to the south and east of a TUTT cell in the WNP is often associated with the monsoon trough, and the TUTT cell (or a chain of TUTT cells) acts to modulate the distribution of cloudiness along the axis of the trough, and also acts to produce an accentuated sinusoidal pattern to the outflow cirrus on the northern side of the monsoon cloud band.

Sadler (1967) proposed that the TUTT (with its embedded TUTT cells) was the primary source for disturbances (e.g., inverted troughs, isolated clusters of CB, etc.) in the trade wind flow. Sadler (1967) also credits TUTT cells with the capacity to induce TC genesis. TUTT-induced TC genesis was envisioned by Sadler to be the result of the distal penetration of the TUTT cell cyclonic circulation to the lower levels, thereby initiating deep convection which, through the release of latent heat, gradually converted the TUTT cell into a warm-core low (i.e., a TC). In two later papers (Sadler 1976, 1978), the role of the TUTT (and of TUTT cells within it) is relegated to one of contributing to the development of a TC by providing a region of persistent upper-level divergence to

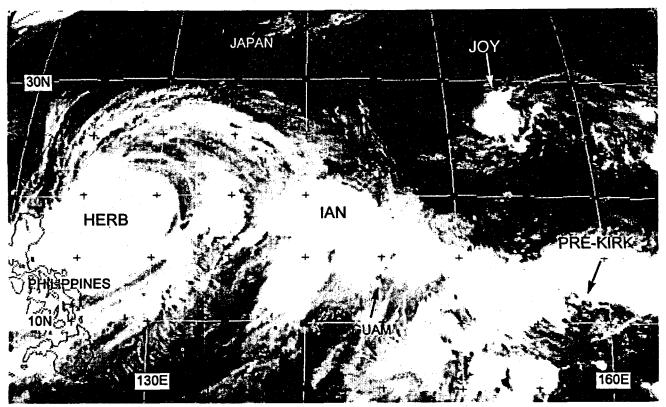


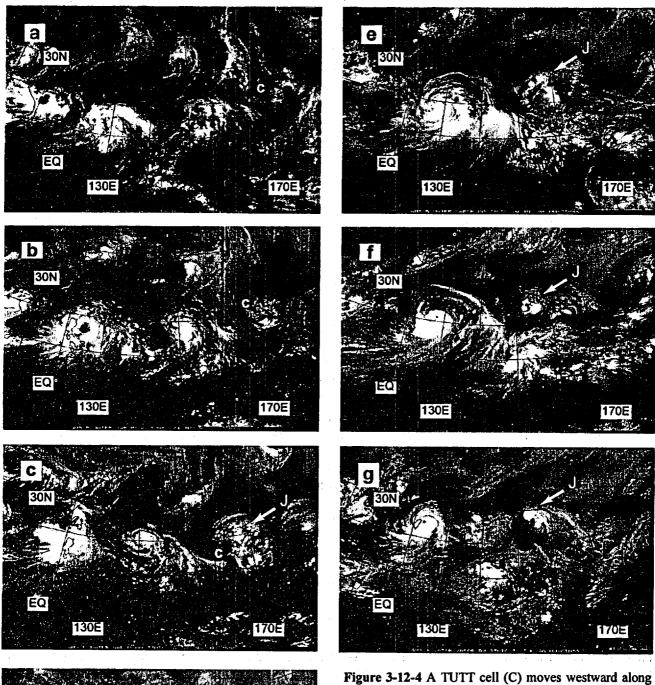
Figure 3-12-3 A characteristic typical of TUTT-induced tropical cyclones, Joy is isolated in the relatively cloud-free region of easterly low-level wind flow to the north of the monsoon cloud band (291331Z July infrared GMS imagery).

initiate and maintain deep convection. The TUTT cell also creates an efficient outflow channel for the incipient TC. In this scenario, the TC is usually located to the south or southeast of the TUTT, or a TUTT cell that propagates in tandem with it.

In our investigations of the role of the TUTT — and in particular, TUTT cells — in TC formation in the WNP, we have observed a process whereby a TC forms (sometimes rapidly) near the core of a TUTT cell. This process is similar to Sadler's (1967) distal mechanism of TUTT-cell induced TC formation. Careful observation has shown that the isolated convective cloud cluster (i.e., a mesoscale convective system) that forms a TC near the TUTT cell, does so not directly in the core of the TUTT cell, but usually within 200 to 400 km to the east through north of the upper-level circulation center of the TUTT cell where the upper-level flow is diffluent and anticyclonically curved. Also, it is here, on the northern side of the TUTT cell, that both the upper-level and lower-level flow is easterly resulting in a region of low vertical wind shear. Another typical characteristic of these TUTT-induced tropical cyclones is their isolation in the cloud minimum region of easterly wind flow to the north of the monsoon cloud band (e.g., Figure 3-12-3). The origin of Joy from a TUTT cell is well illustrated by water-vapor imagery (Figure 3-12-4a-g).

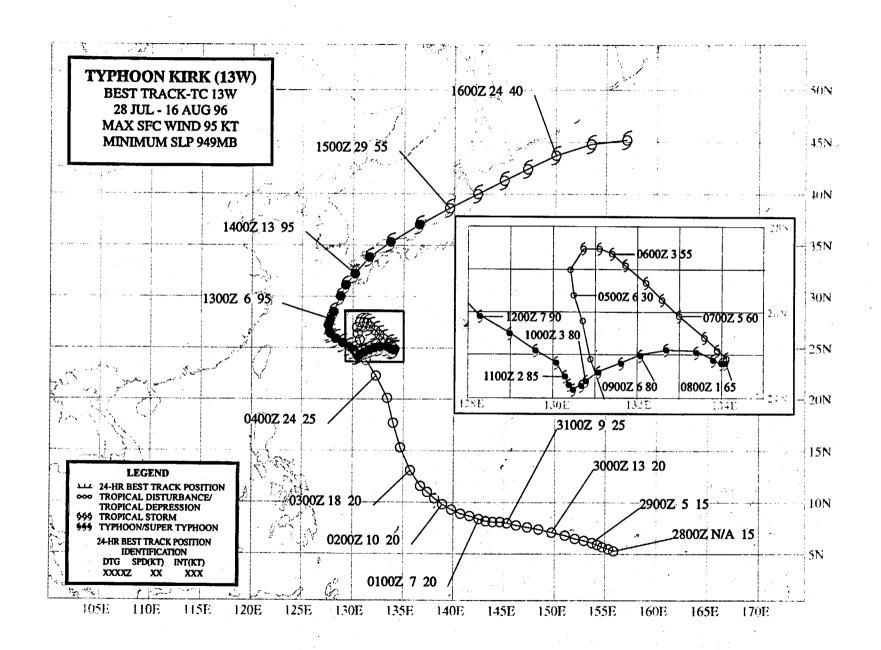
IV. IMPACT

No reports of injuries or damage were received at the JTWC.



G 30N EQ 130E 170E

Figure 3-12-4 A TUTT cell (C) moves westward along 20°N in the WNP and induces the formation of Joy (J): (a) 212331Z July, (b) 240031Z, (c) 260031Z. (d)270031Z, (e) 290031Z, (f) 300031Z, and (g) 310931Z July water-vapor GMS imagery.



TYPHOON KIRK (13W)

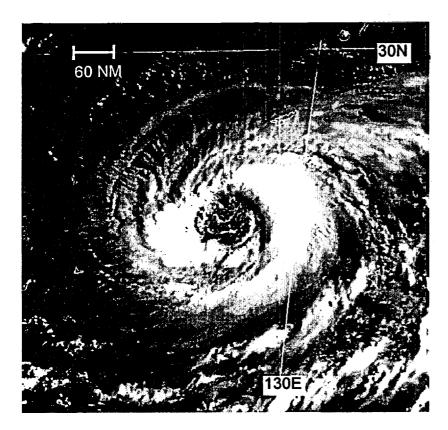


Figure 3-13-1 Kirk exhibits a very large eye as it approaches Okinawa (112331Z August visible GMS imagery).

I. HIGHLIGHTS

Forming from a monsoon depression in the Philippine Sea, Kirk moved on a complex north-oriented track which saw it undergo an unusual anticyclonic loop before passing directly over Okinawa. Kirk was the first of three TCs during 1996 to acquire a very large eye (Figure 3-13-1) — it took a full 12 hours for Kirk's 70-nm (130-km) diameter eye to pass over Okinawa. The NEXRAD Doppler radar at Kadena AB afforded a rare chance to investigate a typhoon with a ground-based radar from within the eye. After passing over Okinawa, Kirk moved north and passed over southern Japan where extensive property damage and loss of life were reported.

II. TRACK AND INTENSITY

During the final days of July, the tropical disturbance which became Kirk formed at the end of the monsoon trough to the southeast of Guam while both Herb (10W) and Joy (12W) were still active. During the first few days of August, Herb moved into China, Joy moved into the midlatitudes, and the pre-Kirk tropical disturbance was subsumed by a larger monsoon depression that formed in the Philippine Sea (Figure 3-13-2). Slow to consolidate (and undergoing a major structural change), the pre-Kirk disturbance received a total of five Tropical Cyclone Formation Alerts (TCFA) prior to the issuance of the first warning.

The tropical disturbance which became Kirk was first mentioned on the Significant Tropical Weather Advisory valid at 290600Z July, when synoptic data showed that a weak low-level circulation accompanied an area of convection near Chuuk. The first TCFA was issued valid at 292100Z when amounts of deep convection increased near the persistent low-level circulation center (LLCC). The second TCFA was issued valid at 300730Z to reposition the alert box for the continued westnorthwestward motion of the pre-Kirk disturbance. This disturbance was undergoing large fluctuations in the amounts and organization of its deep convection which consisted of an ensemble of mesoscale convective systems (MCS), a hallmark characteristic of a monsoon depression. At 310300Z, the second TCFA was canceled when convection became more poorly organized. On 01 August, extensive amounts of deep convection formed in the Philippine Sea — disorganized bands and small clusters of MCSs occupied an area within a box bounded by 5°N to 25°N and 130°E to 150°E. On 02 August, this large area of deep convection became organized as a large monsoon depression (Figure 3-13-2) comprised of an enormous ensemble of MCSs associated with a large, but weak, cyclonic circulation and extensive cirrus outflow organized into an anticyclonic pattern. A third TCFA was issued valid at 020030Z August when scatterometer data indicated the presence of an LLCC with monsoon gales located to its southeast. Remarks on this TCFA include:

"... A disturbance resembling a monsoon depression is located within the monsoon trough. Scatterometer data [from an earlier pass of the ERS-1 satellite] supports the presence of a closed low-level circulation center, with gale force winds located 180 nm to the southeast of the circulation. These winds are associated with a surge in the monsoon..."

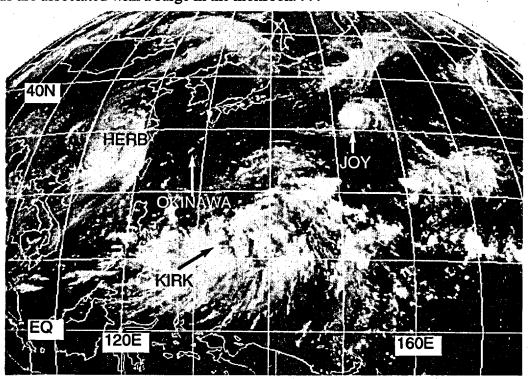


Figure 3-13-2 The monsoon depression in the Philippine Sea from which Kirk developed (020631Z August infrared GMS imagery).

As is often the case with TCs originating from a monsoon depression, the extensive ensemble of MCSs associated with the monsoon depression fluctuated greatly, and were slow to consolidate near a well-defined LLCC. Thus a fourth TCFA was issued valid at 030030Z when satellite

imagery could not confirm the presence of a well-defined LLCC, and deep convection was still widely distributed and not showing signs of consolidation. The fifth, and last, TCFA was issued valid at 031100Z in order to reposition the alert box to encompass an area of deep convection that was becoming organized outside the alert box specified by the fourth TCFA. This area of deep convection increased in organization near the LLCC, and the first warning on Tropical Depression (TD) 13W was issued valid at 031800Z.

Moving on a north-oriented track within a monsoon trough which had become reverse oriented (see Appendix A), TD 13W gradually slowed its forward speed, and on 06 August, it turned toward the southeast as it began an anticyclonic loop in its track. On the warning valid at 060000Z, TD 13W was upgraded to Tropical Storm Kirk.

While executing its anticyclonic loop, Kirk intensified and became a typhoon at 080000Z. At this time, it began to move on a generally westward heading toward Okinawa. Before reaching Okinawa on 12 August, Kirk's eye became extremely large (see Discussion section). Radar and satellite measurements of its eye diameter exceeded 60 and 70 nm respectively during most of 12 August (Table 3-13-1).

After passing over Okinawa, Kirk turned toward the north, its eye diameter decreased, and the system reached its peak intensity of 95 kt (49 m/sec) (Figure 3-13-3) while accelerating along a

recurving track that brought it across southern Japan and into the Sea-of -Japan. Kirk dropped below typhoon intensity as it skirted northeastward along the coast line on the Sea of Japan side of Honshu. On 15 August, Kirk crossed the northern end of Honshu from west to east and entered the Pacific. The system then accelerated within the midlatitude westerlies, became extratropical, and the final warning was issued valid at 160600Z August.

Table 3-13-1 EYE DIAMETER OF KIRK FROM NEXRAD AND SATELLITE DURING PASSAGE OVER OKINAWA.				
DIG (Z)	NEXRAD eye diameter (nm)	Satellite eye diameter (rm)		
120501		· 76		
120530	-	. 70		
120630	ika sa marangan kacamatan kacamatan kacamatan kacamatan kacamatan kacamatan kacamatan kacamatan kacamatan kacam	70		
120640	70	<u> </u>		
120830	· · · · · · · · · · · · · · · · · · ·	67		
120930	61	71		
120942	·	70		
121030	63	74		
121130		77		
121151	63			
121230	55	70		
121240	 ·	65		
121330	53	70		
121430	51	68		
121530	60	68		
121630	66	67		
121730	53	70		
121815	58	-		

III. DISCUSSION

a) Unusual motion: a synoptic-scale anticyclonic loop

It is well known that TCs tend to meander or oscillate about a mean path. These oscillations cover a wide range of scales and can take on several forms, including small-amplitude and short-period trochoidal oscillations around an otherwise smooth track, larger-scale and longer-period meanders, more erratic and nonperiodic meanders (occasionally including stalling, or small loops), or highly-erratic wandering with no well-defined track. A wide range of scales are involved as the meanders vary in period from a few days to less than an hour and have amplitudes up to a few hundred kilometers.

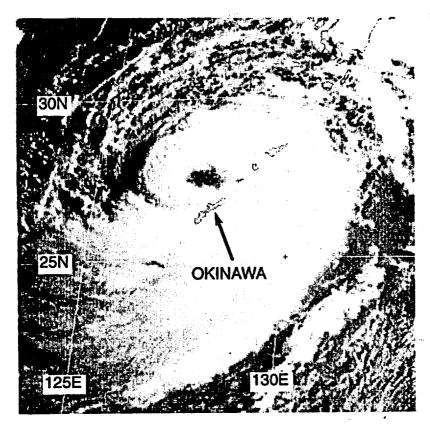


Figure 3-13-3 Kirk reaches its peak intensity of 95 kt (49 m/sec) (122131Z August visible GMS imagery).

During the two days prior to passing over the island of Okinawa, Kirk executed an anticyclonic loop with a diameter of approximately 300 nm (550 km). Well-defined looping of a TC, whereby the looping motion results in the TC recrossing its track, is unusual. According to Holland and Lander (1993), medium-scale meanders with period greater than one day and amplitude of several tens to hundreds of kilometers tend to have an equal distribution of cyclonic and anticyclonic rotation. There is a strong tendency toward exclusively cyclonic rotation at shorter periods as confirmed by an examination of 17 radar tracks of TCs provided by Meighen (1987): seven of these had no clearly discernible oscillation, and the remainder contained 23 small-scale meanders, all of which were cyclonic.

Potential mechanisms for the

larger meanders include interactions with surrounding weather systems such as other TCs, TUTT cells, and synoptic-scale troughs and ridges in the subtropics or midlatitudes. During the period of its anticyclonic meander, Kirk probably interacted with other circulations in the monsoon trough and with a high-pressure system to its north. While Kirk was executing its anticyclonic loop, the monsoon trough had lifted to a very high latitude (Figure 3-13-4) and had become reverse-oriented along the portion of it that contained Kirk. Reverse orientation of the monsoon trough is often associated with north-oriented motion of its associated TCs (Lander, 1996). While this may be a satisfactory explanation for Kirk's overall northward drift, it does not offer much insight on the slow anticyclonic loop Kirk made during the period 050000Z through 120000Z. Possible explanations for this loop include an interaction of Kirk with other low-pressure systems along the reverse-oriented monsoon trough, and the affects of a midlevel anticyclone which passed slowly to Kirk's north during this time period. Once the midlevel high moved eastward into the Pacific, Kirk recurved and entered the midlatitude westerlies.

b) Extremely large eye

In Dvorak's analysis techniques (Dvorak 1975, 1984), the eye of a TC is considered to be small if its satellite-observed diameter is less than 30 nm (55 km), average if between 30 nm and 45 nm (55 km and 85 km), and large if greater than 45 nm (85 km). Kirk's satellite-observed eye diameter was in excess of 70 nm (150 km) during much of 12 August (the day it passed over Okinawa). This very large eye required 12 full hours to pass directly across Okinawa. Kirk was one of three TCs during 1996 — the others were Orson (19W) and Violet (26W) — which possessed, at some time during their evolution, an eye with an exceptionally large diameter (on the order of 75 nm).

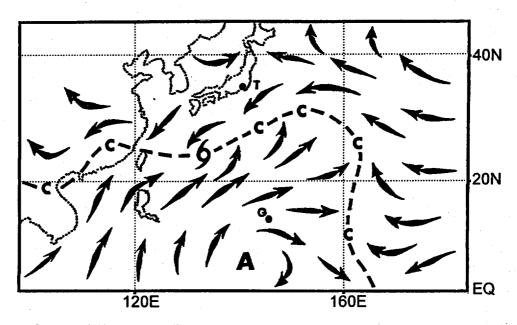
Eye diameters on the order of 75 nm, or greater, are not common. None were observed during 1995. One of the TCM-90 TCs — Abe — possessed an eye with an exceptionally large diameter of about 80 nm. The unusual form of these TCs on satellite imagery led to their being called "truck tires" by JTWC satellite analysts and forecasters.

In a survey of past ATCRs, the largest eye diameter ever reported was that of Typhoon Carmen (1960). By strange coincidence, Carmen, like Kirk, passed directly over Okinawa. Carmen's eye diameter, as measured by the weather radar at Kadena was 200 statute miles (175 nm; 325 km). Comments in the 1960 Annual Typhoon Report include:

"... Another feature quite unusual about this typhoon was the diameter of its eye. Reconnaissance aircraft frequently reported eye diameters of 100 mi, using as the basis of measurement, surface winds and pressure gradient. However, with respect to wall clouds surrounding the eye, radar photographs taken from the CPS-9 at Kadena AB show quite clearly that on 20 August, the eye had a diameter of approximately 200 mi... The eye diameter of Carmen was probably one of the largest ever reported..."

Kirk, like Carmen, was also viewed by a radar at Kadena: this time a new NEXRAD.

Figure 3-13-4
Schematic illustration of the monsoon circulation which became organized in an unusual pattern as Kirk underwent its anticyclonic loop along its north-oriented track (illustration based on 090000Z August JTWC surface analysis).



c) Kirk's passage over Kadena's NEXRAD

One of only four NEXRAD radar units to be installed in the WNP (the others are on Guam and in Korea), the NEXRAD installed on Okinawa affords an excellent opportunity to gather data on the TCs which frequently pass near or over this island. When Kirk passed directly over Okinawa, it was continuously under surveillance by NEXRAD. The NEXRAD support provided to the JTWC by Kadena base weather personnel was superb. They provided timely, thorough information on center positions, wind distribution and intensity. The most striking aspect of Kirk's radar signature was its large eye. During 12 August, as Kirk passed over the radar site from east to west the eye diameter was reported to have been consistently on the order of 60 nm (110 km) (Figure 3-13-5). This is about 10 to 15 nm less than the eye diameters as derived from satellite imagery during this time (Table 3-13-1). It is common for the eye diameter as observed from satellite to be larger than the radar-observed eye diameter due to the general outward sloping with height of the eye-wall cloud.

Another fascinating aspect of the radar coverage occurred when the radar was exactly in the center of the eye: the Doppler velocity product indicated almost zero velocity along all radials. This is certainly what might be expected, but it may be the first time it has actually been observed. Another feature of the velocity product at this time was a slight asymmetry in the radial velocity which were mostly light inbound to the east-southeast and light outbound toward the west-northwest (i.e., indicative of the motion of the typhoon at that time).

d) Fog in the eye, and other ground observations

In recent years, there has been much debate concerning the possible effects of warmer seasurface temperatures (SST) on the annual numbers and the potential peak intensities of TCs under conditions of a warmer climate. Emanuel (1988) set the theoretical ground work for this problem when he introduced his method for calculating the potential peak intensity of TCs. The potential peak intensity of a TC, in his framework, is largely a function of the difference between the warm SST and the colder temperatures of the upper-level outflow layer. Observationally, there is a relationship between the SST and the upper bound of TC intensity.

Granting for sake of argument that the climate will soon become warmer, and that the SST may become on the order of 1°C higher, a question arose as to the affects of this on TC distribution and intensity. This question was addressed in a special symposium at the third International Workshop on Tropical Cyclones (held in Huatulco, Mexico in 1993). The findings of this symposium (published in Lighthill, et al., 1994) were that any effects of a warmer world would likely be masked by the natural variability in TC distribution and intensity and the natural large-scale factors that govern TC formation and development.

A crucial part of this argument hinges on the physical processes which limit the intensity of a TC. As the intensity of a TC increases, frictional drag and evaporative cooling of sea spray have been suggested as brakes on the continued intensification of the TC. Other limiting factors on intensity may be the efficiency of the deep convection in the eye wall to evacuate the mass of the low-level inflow.

The thermodynamics of the TC are not fully understood. The relative contributions to the energy available to the TC by latent heat release and sensible heat fluxes from the ocean are not fully known. The cooling effects of sea spray which is produced at higher wind speeds has been introduced as an important factor in the energetics of the TC (Kepert and Fairall, 1993).

A tangential sidelight which may have important implications on the debate on the role of sea-surface fluxes on the energetics of TCs is the frequent observation of fog within the eye of TCs. During all TCs which have passed over Guam during recent years, ground fog has been reported in the eye. Observations from Kadena indicate fog was present in the eye of Kirk for the first three hours within the eye. Ramage (1974) discusses the occurrence of fog reported at sea by a ship in the eye of a typhoon (this was under the special condition of the SST having been significantly cooled by the recent passage over the same location by another typhoon). Simpson (personal communication, 1996) indicates ground fog was often reported in the eye of landfalling hurricanes in the United States. The suggested mechanism was sensible cooling of the air within the eye as it passes over land chilled by the rain and wind of the eye wall. Fog in the eye at ground or sea level could have relevance to the thermodynamic arguments concerning TC intensity (e.g., rates of sea-spray evaporation in the inflow layer, and extent of subsidence of warm dry air within the eye).

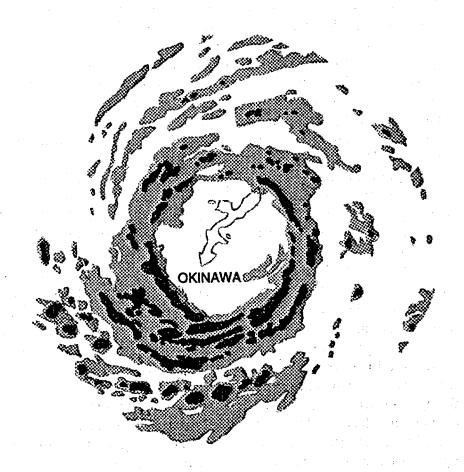
IV. IMPACT

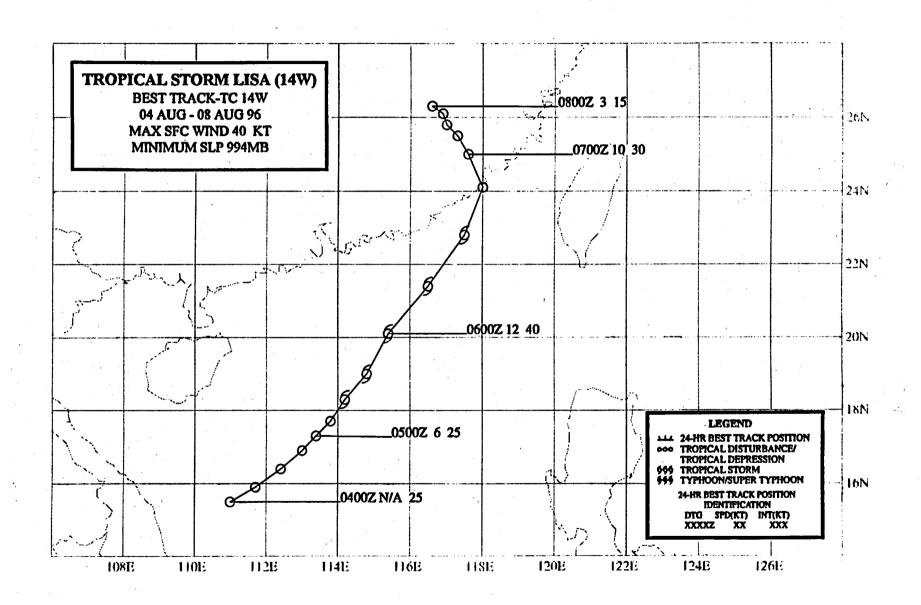
Kirk's impact on Okinawa was largely superficial with many trees blown down, street signs broken, decorative wooden fences knocked over, and street light fixtures twisted or damaged. Some local flooding was reported. Some economic losses were incurred due to the cancellation of normal air service, the closing of shops, and a halting of an oil refinery.

Damage was more extensive, and loss of life was reported, as Kirk moved into southern Japan. There, at least two people were reported killed (a Japanese woman and a U.S. Navy serviceman were swept out to sea by high surf) and 15 injured. Over 100,000 homes were left without electricity.

At the Navy base at Sasebo, superficial damage was reported on some ships, while several other ships dragged anchor. Numerous trees were reported down on the main base, as well as a brief loss of power. At Misawa AB, some aircraft were evacuated and some others secured in hangars, but the effects of Kirk there were minimal, and no damage was reported.

Figure 3-13-5 A radar depiction of Kirk while it was centered over Kadena. Shaded regions indicate reflectivity values of at least 30 dBZ, and the black regions indicate reflectivity values of at least 40 dBZ. (Depiction based upon the 120611Z NEXRAD composite reflectivity product).





TROPICAL STORM LISA (14W)

In early August, as Herb (10W) moved into China, and Joy (12W) recurved into the midlatitudes, deep convection began to increase in the monsoon trough which stretched across the Philippines into the Philippine Sea. On 02 August, deep convection consolidated within two regions, one (which became Kirk (13W)) in the Philippine Sea, and the other (which became Lisa) over the Philippines. The area of deep convection in the Philippine Sea became a monsoon depression and moved north, while the area of convection over the Philippines moved westward and became a monsoon depression in the South China Sea (SCS). Indications of organization of the deep convection over the SCS were first mentioned on the 040600Z Significant Tropical Weather Advisory. When satellite imagery and synoptic data indicated the presence of a low-level cyclonic circulation within an area of persistent deep convection (Figure 3-14-1a), the JTWC issued a Tropical Cyclone Formation Alert, valid at 050430Z. The first warning on Tropical Depression (TD) 14W soon followed (valid time 050600Z) based on satellite intensity estimates of 25 kt (13 m/sec). With Kirk (13W) east of Okinawa, the axis of the monsoon trough became reverse oriented, and TD 14W moved northeastward toward Taiwan. The upgrade of TD 14W to Tropical Storm Lisa at 060000Z was based upon synoptic reports of gales near the LLCC at a time when the satellite signature was not well-organized. Late in the day on 06 August, the persistent deep convection associated with Lisa moved over land in southeastern China. Microwave imagery (Figure 3-14-1b), however, indicated that the LLCC was sheared to the east of this convection and remained offshore through the night. On the morning of 07 August, synoptic data indicated the LLCC of Lisa had moved ashore in China, and the final warning was issued valid at 070000Z.

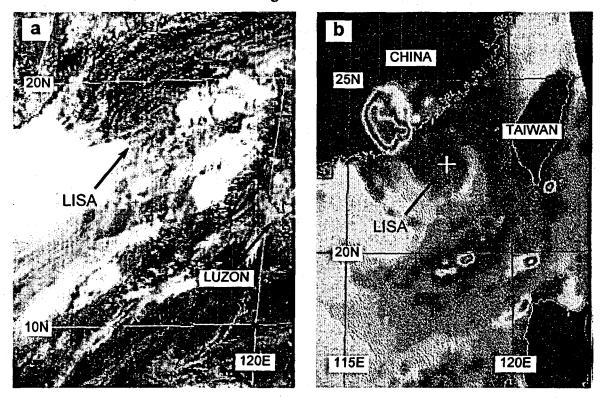
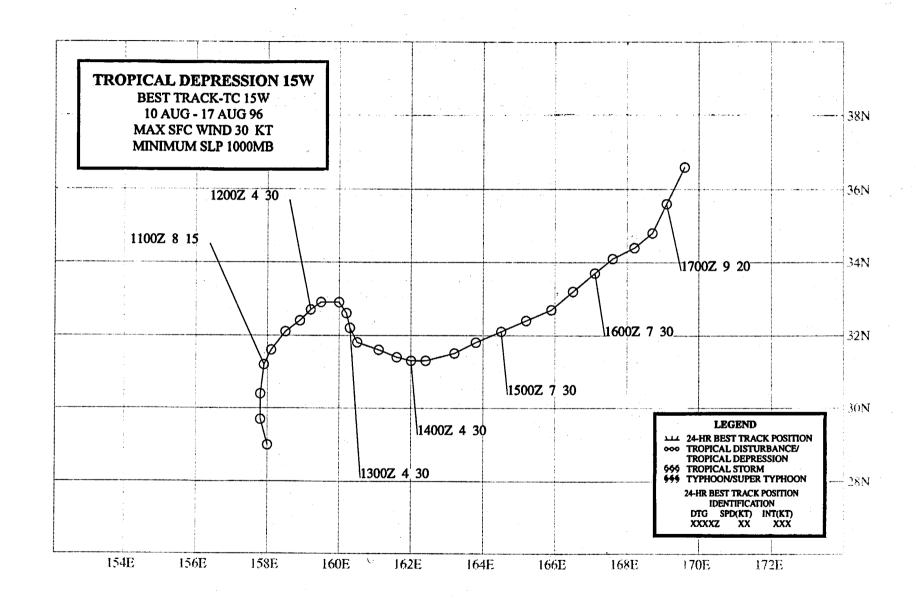


Figure 3-14-1 (a) A well defined LLCC is exposed amidst the ensemble of MSCs associated with a monsoon depression in the SCS (050031Z August visible GMS imagery). (b) Lisa's LLCC is clearly located over water to the southeast of the deep convection in microwave imagery (061415Z August 85 GHz horizontally-polarized microwave DMSP imagery).



TROPICAL DEPRESSION 15W

Tropical Depression (TD) 15W originated in the subtropics at a time when the monsoon trough was displaced far to the north of normal (see Figure 3-13-4 in Kirk's summary for a graphic depiction of this unusual low-level flow pattern). TD 15W had an unusual structure comprised of an extensive region of low-level cloud lines surrounding a small area of deep convection (Figure 3-15-1a). First identified on the 100600Z August Significant Tropical Weather Advisory, the system drifted slowly northward and became better organized. Based on satellite intensity estimates of 25 kt (13 m/sec), the first warning was issued, valid at 120600Z. Moving generally toward the east-northeast, the system maintained its unusual cloud pattern. The peak intensity of 30 kt (15 m/sec) — as estimated from satellite imagery, and confirmed by a scatterometer pass (Figure 3-15-1b) — was maintained for several days. When the system lost its deep convection, and the extent and organization of the low-level cloud lines decreased, the final warning was issued valid at 160600Z.

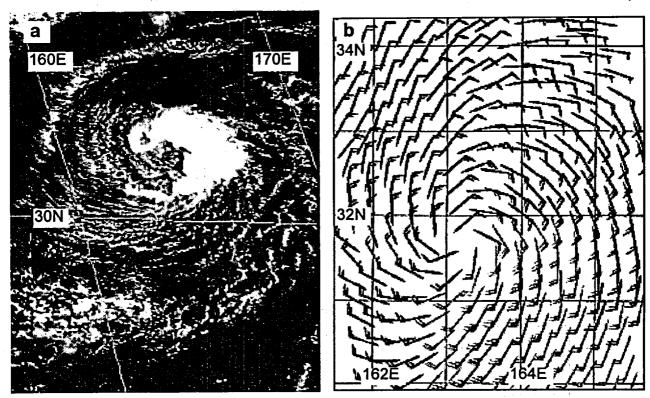
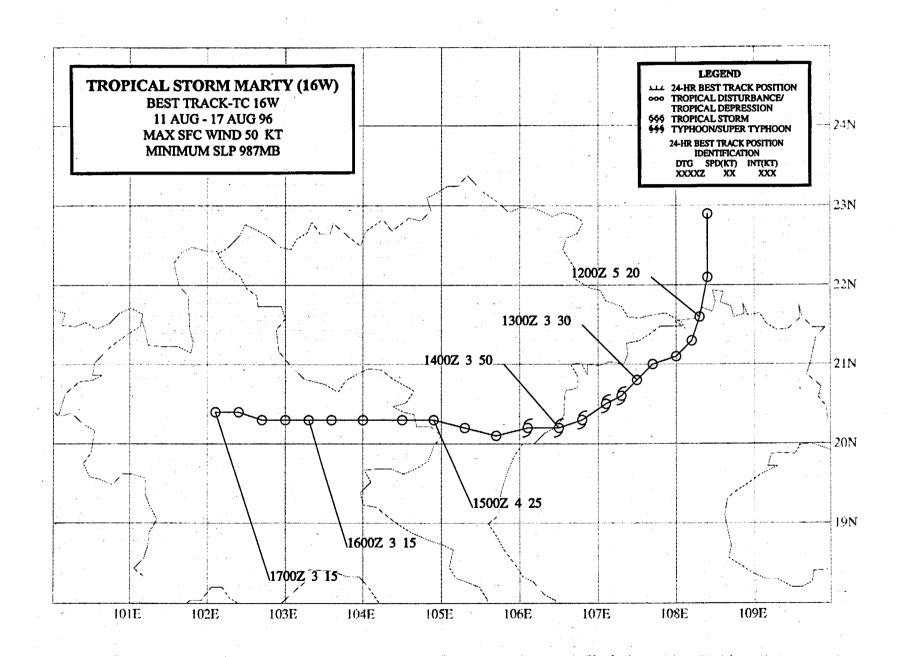


Figure 3-15-1 (a) Well-defined low-level cloud lines coil tightly around a poorly organized area of deep convection (132331Z August visible GMS imagery). (b) A region of 25- to 30-kt (13- to 15-m/sec) winds was detected by scatterometry in the southeastern quadrant of TD 15W (141132Z August ERS-2 scatterometer-derived marine surface winds).



TROPICAL STORM MARTY (16W)

I. HIGHLIGHTS

Developing in the Gulf of Tonkin, Marty was a very small tropical cyclone. In real time, satellite intensity analyses did not agree with synoptic data and with news reports of the devastation of Vietnamese fishing boats in the Gulf of Tonkin where 125 people were reported killed and another 107 missing. Marty was upgraded to a tropical storm after it had crossed the coast because synoptic data indicated that gales were present along the coast and over waters to the east. The final best track increases Marty to a tropical storm while it was over the Gulf of Tonkin and raises its peak intensity from 35 to 50 kt.

II. TRACK AND INTENSITY

Marty originated in the monsoon trough over land in southwestern China. Though first mentioned on the 130600Z August Significant Tropical Weather Advisory, the area of deep convection that became Marty could be identified (in post analysis) as early as 11 August (Figure 3-16-1). The pre-Marty disturbance moved southward into the Gulf of Tonkin and intensified. Based on indications from satellite and synoptic data that the system had moved over water, the first warning (valid at 130600Z August) was issued on Tropical Depression (TD) 16W. The TD then turned more to the west, and shortly after 140000Z (after a short path over water) it made landfall about 60 nm (110 km) south of Hanoi. Although over land at 140600Z, TD 16W was upgraded to Tropical Storm Marty when synoptic data indicated that gales were occurring along the coast and over water to the east. The upgrade to a tropical storm after the system made landfall is unusual, but it was realized the intensity of Marty had been underestimated. Ironically, the warning that upgraded Marty to a tropical storm was also the final warning, since the system was then weakening over land.

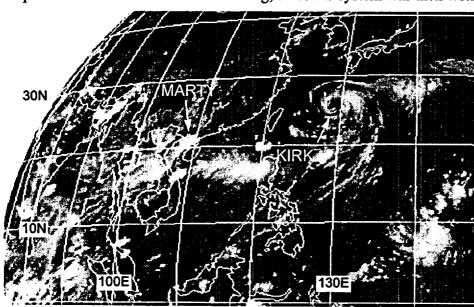


Figure 3-16-1 The disturbance that became Marty formed in southwestern China along the axis of the monsoon trough (111831Z August infrared GMS imagery).

III. DISCUSSION

The importance of post analysis

A comprehensive post analysis provides insight into the behavior of a TC in a specific situation. The goal of such an analysis is to produce a more exact, definitive product from the usually vague, imprecise, and often incomplete real-time data input. In the case of Marty, there was very lit-

tle synoptic data available in the region. When the TC made landfall in Vietnam, crucial synoptic data (including a scatterometer pass) became available which indicated Marty was more intense than



Figure 3-16-2 Exhibiting a CDO pattern, the very small Marty attains its peak intensity of 50 kt (26 m/sec) while over the Gulf of Tonkin (132131Z August enhanced infrared GMS imagery).

thought. Also hindering an accurate assessment of Marty's intensity was its small size (Figure 3-16-2) which biased the satellite intensity estimates on the low side. A careful review of Marty was conducted and it included a reassessment of intensity estimates from satellite imagery (Table 3-16-1). Concerning Marty's intensity, the following was noted by the reassessment team:

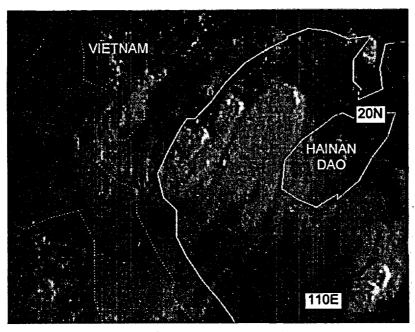
"TS Marty was close to a midget in size. Dvorak [satellite intensity estimates] did not appear to coincide with synoptic data and news reports of 'whirlwind destroying numerous fishing boats with the loss of from 125 to 232 people'. All T number [intensity estimates] . . . were 0.0 [less than 25 kt] except for a T2.0 . . . at 13/1730Z just before it went on shore in Vietnam. Pressures were below 997 mb within 60 nm of the circulation center — lots of room for greater intensity of the cyclone if it was 'truly' a midget".

Figure 3-16-3 is satellite imagery on 13 August originally thought to indicate wind speeds less than 25 kt (13 m/sec), but in post analysis was considered to be indicative of 30 kt (15 m/sec). Figure 3-16-2 (and later visible imagery — not shown) was reassessed to be indicative of an intensity of 50 kt (26 m/sec).

IV. IMPACT

News out of Vietnam claimed that a "whirlwind" capsized fishing boats along the northern Vietnamese coast, killing at least 125 people with another 107 missing and feared dead.

Table 3-16-1 Reanalysis of satellite intensity estimates used to support Marty's best track.				
DTG	New T Number	Intensity (kt)	Old T Number	Intensity (kt)
12/03z	1.0	25	0.0	<25
13/03z	2.0	30	0.0	<25
13/09z	2.5	35	0.0	<25
13/21Z	3.5	55	2.0	30



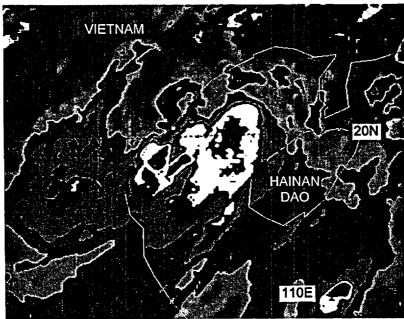
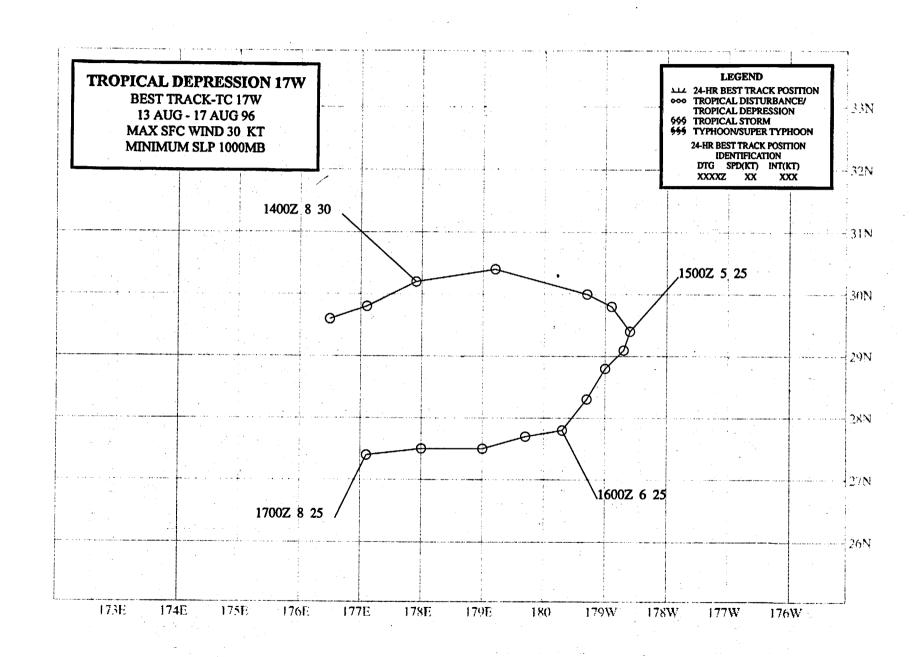


Figure 3-16-3 This satellite imagery of the tropical disturbance that became Marty was reassessed to be indicative of 30 kt (15 m/sec) intensity instead of the original diagnosis of less than 25 kt (13 m/sec) ((a) 130031Z August visible GMS imagery, and (b)130031Z enhanced infrared GMS imagery).



TROPICAL DEPRESSION 17W

Tropical Depression (TD) 17W originated in the subtropics at a time when the monsoon trough was displaced far to the north of normal (see Figure 3-13-4 in Kirk's summary for a graphic depiction of this unusual low-level flow pattern). TD 17W and Tropical Depression 15W formed and developed in this trough simultaneously (Figure 3-17-1). First identified on the 110600Z August Significant Tropical Weather Advisory, the area of deep convection which became TD 17W drifted slowly eastward and became better organized. The first warning was issued, valid at 140000Z when visible satellite imagery revealed a well-defined LLCC to the north of an area of persistent deep convection on the morning of 14 August (Figure 3-17-1). Whereas TD 15W drifted east-northeastward into higher latitudes, TD 17W executed an anticyclonic oval-shaped loop (centered at 29°N 179°E) with an average diameter of approximately 200 nm (370 km). After 141200Z, TD 17W moved across the international date line, and the JTWC passed warning responsibility to the Central Pacific Hurricane Center (CPHC). The depression continued east and came within 90. nm (170 km) of Midway Island (WMO 91066) (Figure 3-17-2) and began to weaken. The CPHC issued the final warning valid at 150000Z. At Midway, gusty winds and showers persisted for several days: the automatic remote collector there recorded a peak gust of 35 kt (18 m/sec) and approximately 2.5 inches (64 mm) of rain. TD 17W turned back to the west, recrossing the international date line on 16 August, and dissipated on 17 August.

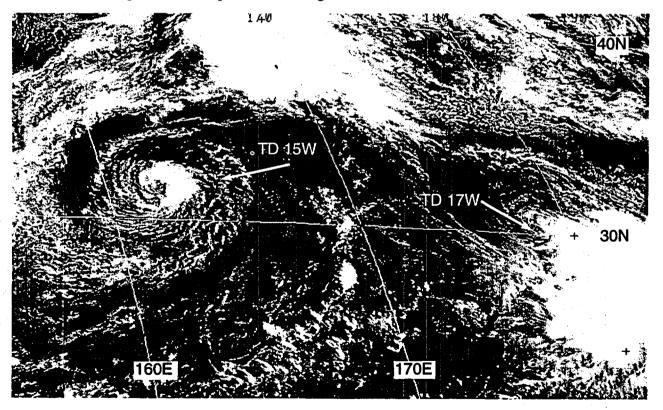
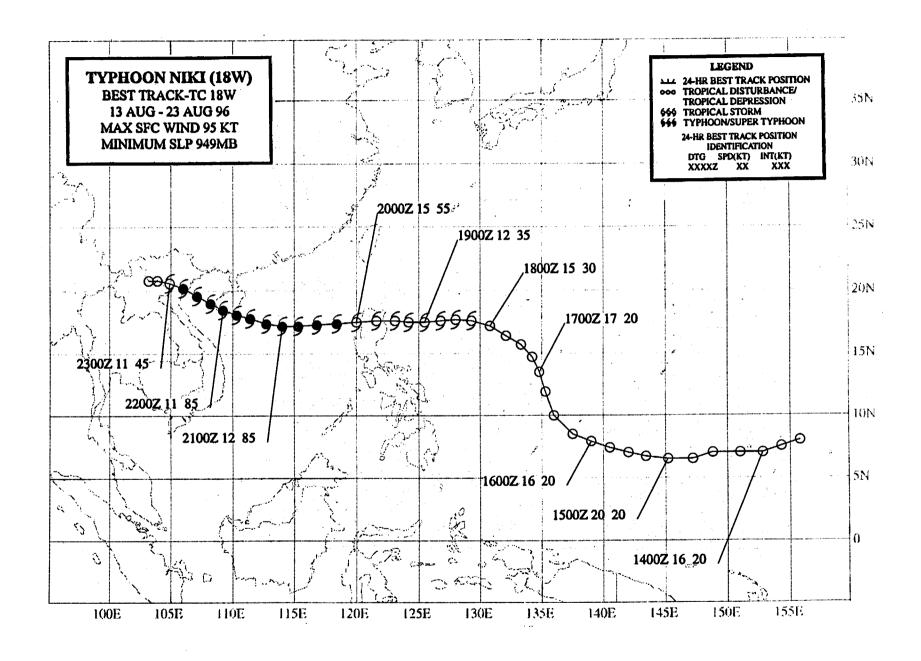


Figure 3-17-1 TD 17W and TD 15W both formed in subtropical latitudes within a monsoon trough which had moved far to the north and east of normal (132331Z August visible GMS imagery).



Figure 3-17-2 TD 17W exhibits a classical Dvorak "shear" type cloud pattern after crossing to the east side of the international date line (141830Z August visible GMS imagery).



TYPHOON NIKI (18W)

I. HIGHLIGHTS

Niki persisted as a weak tropical disturbance for several days as it moved toward the west at low latitude in Micronesia. It did not intensify until it reached the Philippine Sea east of Luzon. Crossing Luzon, it became a typhoon in the South China Sea (SCS) where it crossed the southern tip of Hainan island, and later made landfall in Vietnam south of Haiphong. Early in its life, satellite fixes were consistently north of the synoptic fixes. In the Philippine Sea, a circular exhaust cloud formed near Niki's center.

II. TRACK AND INTENSITY

During the middle of August, the monsoon trough moved to a very high latitude, and a ridge of high pressure to its south produced easterly low-level winds across the deep tropics of the WNP. Within these low-latitude easterly winds, several tropical disturbances formed. The tropical disturbance that became Niki can be traced to a small ensemble of MCSs which appeared in the eastern Caroline Islands on 13 August. This disturbance moved westward (south of 10°N) and, though first mentioned on the 130600Z August Significant Tropical Weather Advisory, there was no definitive evidence that it possessed a LLCC until 15 August when the system had moved due south of Guam. The JTWC issued a Tropical Cyclone Formation Alert (TCFA) at 170600Z August when, according to remarks on the alert:

"Convection surrounding a low-level circulation center has become better organized over the past 6 hours. Water vapor winds courtesy of the University of Wisconsin and synoptic data indicate the presence of an upper-level anticyclone over the LLCC which is enhancing the convective signature..."

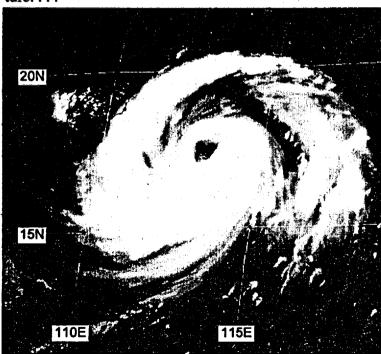


Figure 3-18-1 Typhoon Niki intensifies to 90 kt (46 m/sec) in its track across the South China Sea toward Hainan Island (210424Z August visible GMS imagery).

A second TCFA was issued at 172330Z August (primarily to reposition the TCFA box). The first warning on Tropical Depression (TD) 18W soon followed (valid at 180000Z) based on satellite intensity estimates of 30 kt (15 m/sec). TD 18W was upgraded to Tropical Storm Niki on the warning valid at 190000Z (post analysis pushed this back to 180600Z). Moving nearly due west, Niki passed across the northern end of Luzon during the six-hour period 191600Z to 192200Z. Northern Luzon had very little effect upon Niki's intensity, and as soon as it moved into the SCS, an eye began to form and Niki became a typhoon at 200600Z. The typhoon continued to intensify as it moved across the SCS (Figure 3-18-1), and reached a peak intensity of 95 kt (49 m/sec) at 211800Z just as the system made landfall on the southern end of Hainan Island. Niki's eye became large and ragged as it passed from Hainan into the Gulf of Tonkin. Intensity estimates slowly fell, and the system (at minimal typhoon intensity) made landfall approximately 50 nm (95 km) south of Haiphong on the coast of Vietnam at 221800Z. The final warning was issued valid at 23000Z as the system weakened over land.

III. DISCUSSION

a. Common fix errors for low-latitude tropical depressions

When TCs form at low latitude (i.e., between 5° and 10°N) it is common that the satellite fixes tend to be located to the north of the synoptic fixes (Figure 3-18-2), especially when the TC is very weak and poorly defined. At such times, the satellite fix is often based upon the point of symmetry of anticyclonic cirrus outflow, and the curvature of poorly defined and transient bands of deep convection. A careful post analysis of the synoptic data indicated that the satellite fixes were too far north during the period 13 to 17 August.

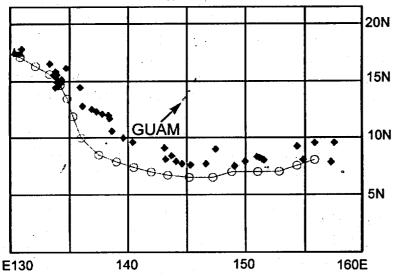


Figure 3-18-2 Based on a reanalysis of synoptic data, Niki's best track (small circles connected by thin line) was moved approximately 100 nm (185 km) to the south of the satellite fixes (black diamonds) during the period 13 to 17 August.

b. The circular exhaust cloud

In the early days of satellite reconnaissance, a peculiar structural feature was sometimes observed during the intensification phase of some TCs: the circular exhaust cloud. The term (coined by Fujita) was used to describe the emergence — in a developing TC - of an extremely tall, nearly circular, and sharply delineated cirrus canopy possessing an overshooting top surrounded by overlapping concentric rings and radial spokes (in visible imagery) which are the manifestation of gravity waves. On the morning of 19 August, a circular exhaust cloud formed near the center of Niki (Figure 3-18-3). Originally thought to represent the

center of the TC (in the context of a small CDO), it was later revealed by aircraft reconnaissance (Black, personal communication; Black, et al., 1986), that the circular exhaust cloud was a "hurricane supercell" with its roots in the primary rainband (or developing wall cloud). Thus, its centroid did not lie over the TC center (Figure 3-18-4). In his work with infrared imagery, Dvorak (1984) noted that the use of IR imagery required the introduction of a new concept — the central cold cover (CCC) — in order to deal with the occurrence of a sudden spreading of cold clouds over the central features of a TC. The circular exhaust cloud may be a particular form of the general phenomenon of the CCC, however, the term "circular exhaust cloud" has fallen into disuse. See Gloria's (09W) summary for a more complete description of the concept of the CCC.

IV. IMPACT

When Niki made landfall in Vietnam, a total of 61 people were reported dead or missing with another 161 injured. Total economic losses were reported to be US \$66 million.

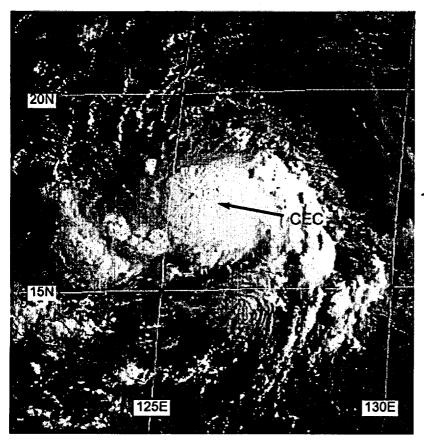
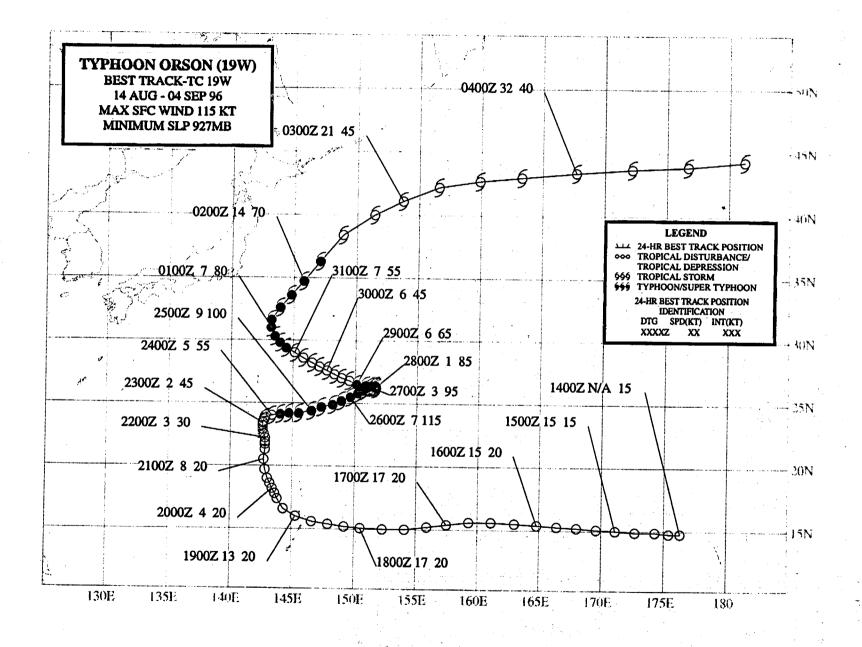


Figure 3-18-4 A schematic illustration of the vertical structure of the circular exhaust cloud.

Figure 3-18-3 A circular exhaust cloud (CEC) appears within Niki's CDO (182224Z visible GMS imagery).



TYPHOON ORSON (19W)

I. HIGHLIGHTS

Tracing its origins to a mesoscale convective system (MCS) which formed on the northeastern side of a TUTT cell, Orson had a complex developmental history including two periods of intensification, the formation of an enormous eye, and a highly erratic track.

II. TRACK AND INTENSITY

The tropical disturbance that became Orson was first noted on the 150600Z Significant Tropical Weather Advisory near 15°N 170°E within a very complex circulation pattern that can best be described as the early stages of the breakdown of the very high latitude monsoon trough within

which Kirk (13W), TD 15W, and TD 17W were located. When the Pre-Orson tropical disturbance formed on 15 August, Kirk (13W) was moving eastward over northern Honshu (and becoming extratropical), and TDs 15W and 17W were dissipating at high latitude (30°N) and east of 160°E. After Kirk became an extratropical low, a ridge of high pressure became established along 27°N. To the south of this ridge the pre-Orson tropical disturbance moved westward, accompanied by a westward moving TUTT cell aloft and to its southwest (Figure 3-19-1). As this disturbance neared the Mariana Island chain, its organization improved and the first of three Tropical Cyclone Formation Alerts (TCFA) was issued at 172230Z August. The second TCFA was issued at 180930Z primarily to move the alert box westward to accommodate the rapid (20 kt) westward translation of the disturbance. At 190330Z, the second TCFA was canceled when much of the deep convection associated with

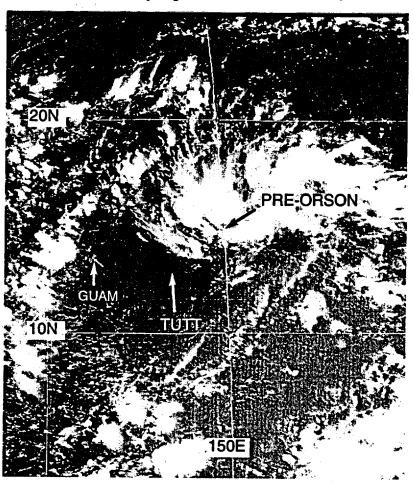


Figure 3-19-1 The tropical disturbance that became Orson was accompanied by a TUTT cell (180031Z August visible GMS imagery).

the system collapsed and became disorganized. During the night of 19 August a large area of deep convection developed over Guam (Figure 3-19-2). This area of convection collapsed, and on the morning of 21 August, a smaller MCS was located north of the collapse region (Figure 3-19-3). Synoptic data indicated the presence of a low-level cyclonic circulation center beneath this MCS, so a TCFA was issued at 202300Z August. Drifting slowly northward, the deep convection persisted,

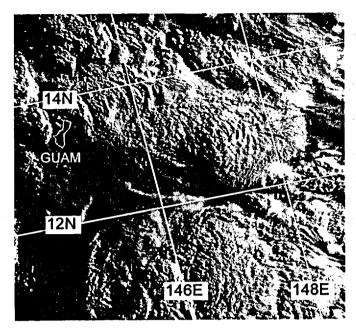


Figure 3-19-2 A very high-resolution image of the cloudtop topography of deep convection that developed near Guam as the pre-Orson tropical disturbance passed to the north (192026Z August high resolution visible DMSP imagery).

and on the night of 21 August, based upon a satellite intensity estimate of 25 kt (13 m/sec), the first warning on Tropical Depression (TD) 19W was issued valid at 211800Z. As TD 19W drifted very slowly to the north it slowly intensified and was upgraded to Tropical Storm Orson at 221200Z. At this time another TC — Piper (20W) — was developing northeast of Orson. With the development of Piper (20W), the monsoon trough became reverse oriented (Figure 3-19-4), and Orson began to move slowly toward the east-northeast along the axis of this trough. Orson intensified while moving east-northeast; becoming a typhoon at 240600Z and reaching a peak intensity of 115 kt (59 m/sec) at 250600Z (Figure 3-19-5). Thereafter, the system weakened as concentric (but ragged) eye walls formed, and the forward motion slowed as high pressure built to the north and east of the typhoon.

On the morning of 29 August, the system lost its eye, and it was downgraded to a tropical storm on the warning valid at 290600Z. Under the influence of a ridge to its north, Orson began to track toward the northwest. While on this leg of its erratic track, the system underwent a remarkable structural evolution: several distinct MCSs began to orbit a large (100 nm diameter) central cloud-minimum area (Figure 3-19-6a, b). Its intensity estimate had bottomed out at 45 kt (23 m/sec) at this time. As the MCSs consolidated into a more contiguous cloud band around the very large ragged eye (Figure 3-19-7), the system once again rose to typhoon intensity, and reached a second relative intensity maximum of 80 kt (41 m/sec) at 311800Z. After reaching its second peak of intensity, Orson recurved and entered the accelerating westerly steering flow north of the subtropical ridge. The final warning was issued valid at 030600Z September as the system transitioned into an extratropical low.

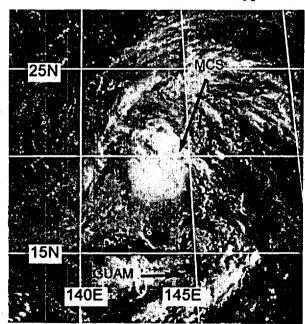


Figure 3-19-3 After the area of deep convection near Guam collapsed, a new MCS (accompanied by a LLCC) developed further to the north (202131Z August visible GMS imagery).

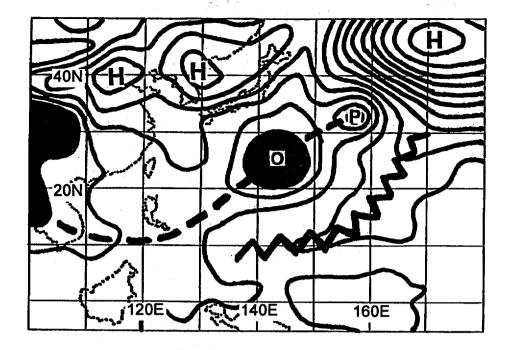


Figure 3-19-4 With the formation of Piper (20W) (P), it was clear that the monsoon trough (thick dashed line) had become reverse oriented. Influenced by the southwest monsoon flow between the trough axis and a ridge (bold zigzag line) which had become established in low latitude, Orson began to move to the eastnortheast on the first leg of its "S" track (isobars at 2 mb intervals adapted from the 241200Z August NOGAPS SLP analysis).

III. DISCUSSION

a. Unusual motion

Orson's erratic motion can be described as a special variant of the north-oriented track type: the "S" track. The north-oriented track was first recognized by the Japan Meteorological Agency (JMA) (1976). Carr and Elsberry (1996) renamed this track type as "poleward oriented" to make the term appropriate for both the Northern and Southern hemispheres. Lander (1996) further elaborated on the characteristics of north-oriented tracks, with a special emphasis on "S"-shaped tracks. "S" motion is poleward-oriented motion of a Northern Hemisphere TC that features eastward motion at low latitude, a later bend to the north or northwest, and then eventually northeastward motion as the TC enters the mid-latitude westerlies. Most cases of "S" motion (including that of Orson) occur when a TC is located along the axis of a reverse-oriented monsoon trough. Surprisingly, the Navy's dynamic models often handle "S" motion (and poleward-oriented motion in general) quite well (Carr, personal communication). Indeed, NOGAPS and GFDN did a good job in predicting the erratic motion of Orson.

b. Very large eye

Orson was one of three TCs during that acquired very large eyes during 1996 — the other two were Kirk (13W) and Violet (26W). Once the large ragged clearing within the ring of MCSs was interpreted as an eye, its diameter on satellite imagery ranged from 70 nm (130 km) to 102 nm (190 km) (Table 3-19-1).

IV. IMPACT

No reports of damage or injuries were received.

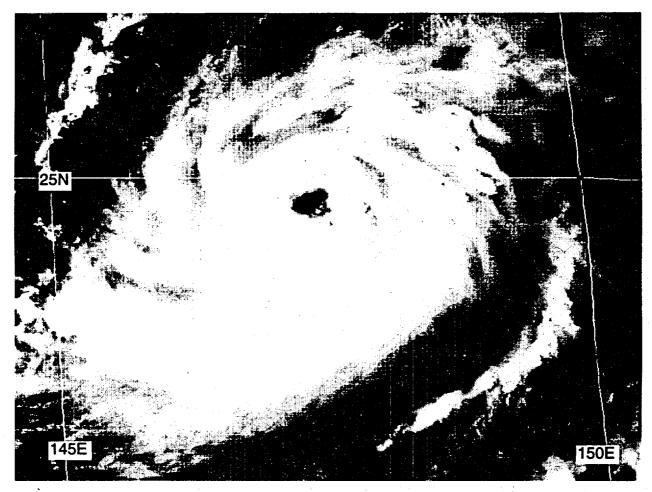


Figure 3-19-5 Orson at its peak of 115 kt (59 m/sec) (250531Z August visible GMS imagery).

Table 3-19-1		OF ORSON FROM SATELLITE DURING RIOD OF INTENSIFICATION.
	IID DECOMD II	
DTG (Z)	T Number	Satellite eye diameter (nm)
301042	3.5	98
301130	3.5	84
301610	3.5	81
301730	3.5	75
310530	4.0	75
310830		74
311130	4.0	84
311559	4.0	70
312030		77
312330	4.5	90
010230		102
010530	4.0	94
010830		98

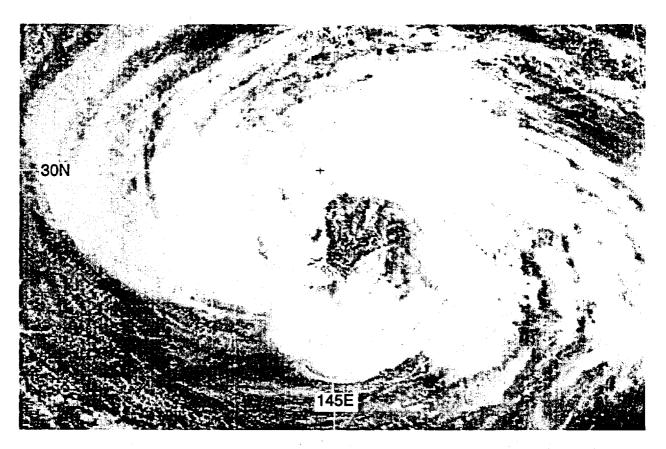
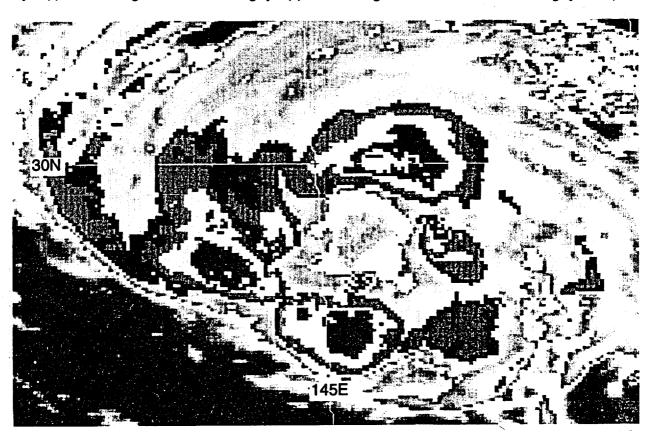


Figure 3-19-6 A ring of MCSs orbit a central clear region as a precursor to the formation of Orson's very large eye. (a) 302131Z August visible GMS imagery. (b) 302131Z August enhanced infrared GMS imagery.



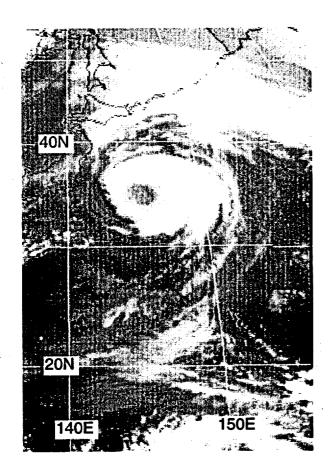
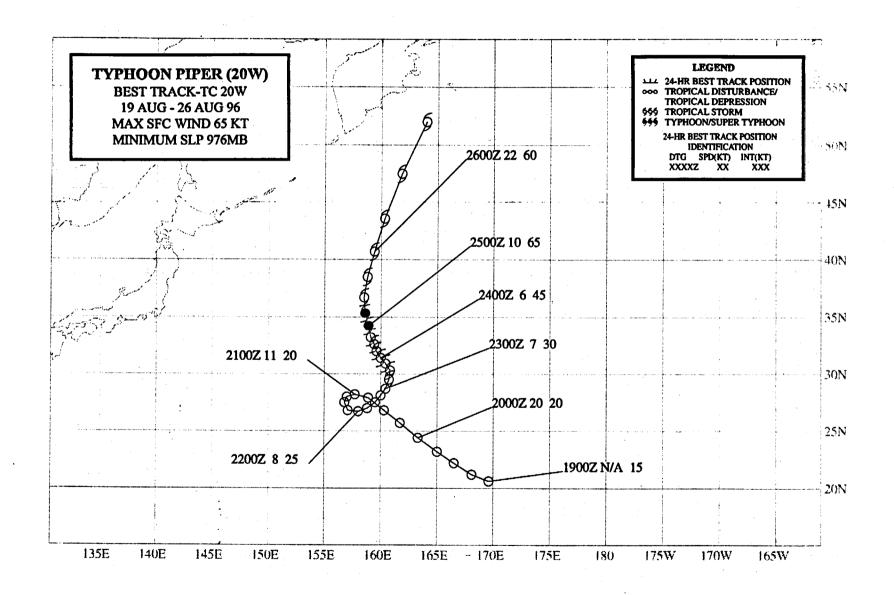


Figure 3-19-7 Orson's very large eye evokes the analogy of a "truck tire" rolling across the ocean (012231Z September infrared GMS imagery).



TYPHOON PIPER (20W)

I. HIGHLIGHTS

Piper was another of the TCs of 1996 which originated directly from a TUTT cell. It was a very small TC — the smallest in the WNP during 1996. Developing at a relatively high latitude to the east of Orson (19W), Piper was located at the eastern end of a reverse-oriented monsoon trough (RMT). Typical of TCs associated with a RMT, Piper's motion was north oriented.

II. TRACK AND INTENSITY

During 19 August, a well-defined TUTT cell was moving westward along 25°N and had crossed 165°E. Mesoscale convective systems populated the eastern through northern segment of a curved moisture band that wrapped into this TUTT cell (Figure 3-20-1a). Synoptic data at 190000Z indicated that a weak low-level cyclonic circulation was located west of this cloud band and close to the estimated center of the TUTT cell, prompting its inclusion on the 190600Z August Significant Tropical Weather Advisory. During the next two days, the low-level cyclonic circulation became associated with an area of deep convection. On 22 August, the deep convection consolidated under the anticyclonically curved flow on the eastern side of the TUTT cell, and scatterometry indicated the wind speeds had increased to 20 kt (10 m/sec) on the north side of the accompanying low-level circulation center (LLCC). This prompted JTWC to issue a Tropical Cyclone Formation Alert valid at 221500Z.

On 23 August, persistent deep convection in the eastern quadrant of the TUTT cell became coupled with well-defined anticyclonic flow aloft. The persistence of deep convection and its increased organization prompted the first warning on Tropical Depression (TD) 20W valid at

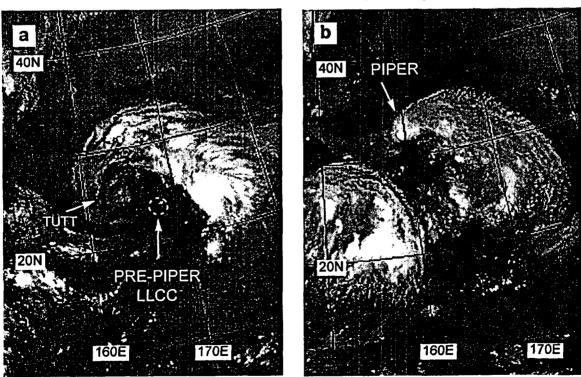


Figure 3-20-1 A westward moving TUTT cell (a) induces the formation of Piper (b). (192131Z August water-vapor GMS imagery and 240031Z August water-vapor GMS imagery respectively).

230000Z. Synoptic data at this time showed the monsoon westerlies had extended to the LLCC of TD 20W, creating a reverse-oriented monsoon trough which included the larger Orson (19W) to the west. Based on a satellite intensity estimate of 35 kt (18 m/sec), TD 20W was upgraded to Tropical Storm Piper on the warning valid at 230600Z. With a ridge located to its southeast, and a blocking high to its northeast, Piper moved on a north-oriented track.

Late on 24 August, Piper's small CDO moved north, became detached from the monsoon cloud band, and intensified. At 250000Z, Piper acquired a visible eye, and reached its peak intensity of 65 kt (33 m/sec) (Figure 3-20-2). Piper retained its small 7-nm (13-km) eye for about 12 hours (Figure 3-20-3a, b). During 26 August, Piper's central convection became a small well-defined CDO (Figure 3-20-4), as it accelerated to the north-northeast and slowly weakened. Late on 26 August, Piper's forward motion increased to more than 40 kt (75 km/hr) as it merged with a frontal cloud band which stretched southward from a low over the Kamchatka peninsula. The final warning was issued valid at 260600Z when Piper's CDO became associated with the frontal cloud band. Post analysis indicated Piper's CDO could be followed for an additional 12 hours as it sped northward within the frontal cloud band, and therefore, the final best track continues until 261800Z.

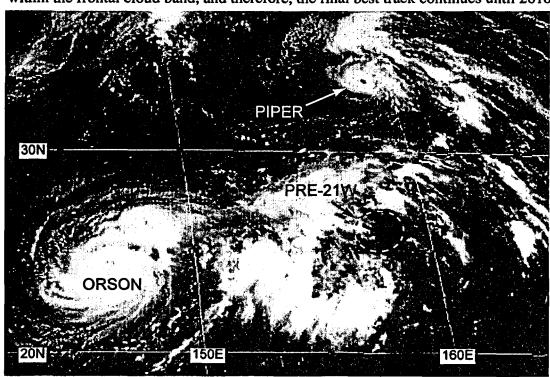


Figure 3-20-2 Piper at its peak intensity of 65 kt (33 m/sec) (242331Z August visible GMS imagery).

III. DISCUSSION

a. Tropical cyclogenesis induced by a TUTT cell

Piper originated directly from a TUTT cell (see Joy's (12W) summary for a more complete description of tropical cyclogenesis induced directly by a TUTT cell). This is well illustrated by water-vapor imagery (Figure 3-20-1a, b). Water-vapor imagery has only been available since the GMS-5 satellite became operational during June of 1995. It has allowed a greatly improved presentation of TUTT cells, and their movement and evolution can now be studied as never before. Water-vapor imagery should open new opportunities for research on the effects of the TUTT and its associated TUTT cells on TC genesis and TC development.

b. Small size

Like most TCs that form at high latitude in association with TUTT cells, Piper was a very small TC — the smallest of 1996. The diameter of its dense cirrus cloud shield was less than 100 nm (185 km) (Figure 3-20-3a, b), and it encompassed a very small eye whose diameter was 7 nm (13 km) on satellite imagery. As with many very small TCs, the intensity forecasts erred on the low side: on the first eight warnings (issued at six-hour intervals from 230000Z August to 241800Z August), the 24-hour intensity was under-forecast by anywhere from 5 to 25 kt; the 48-hour intensity was under-forecast by as much as 30 kt (15 m/sec).

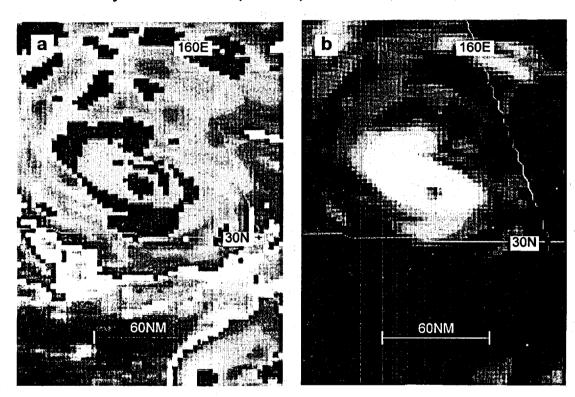


Figure 3-20-3a, b Piper was a very small TC — the smallest of 1996. Its eye was only 7 nm (13 km) in diameter, and its dense cold cirrus shield had a diameter of less than 100 nm (185 km). (a) 250931Z August enhanced infrared GMS imagery, and (b) 250931Z August high-contrast infrared GMS imagery.

c. Development over cool SST

Relatively few TCs in the WNP first attain typhoon intensity poleward of 30°N — during the 25-year period 1970 to 1994 only thirty-one of 729 TCs (4%) which formed in the WNP first attained 65-kt (33-m/sec) intensity at, or north, of 25°N; only twelve at, or north, of 30°N; and only one north of 35° N. Piper first attained 65-kt (33-m/sec) intensity at 34°N. It remained a typhoon for approximately nine hours, and fell below typhoon intensity after crossing 35°N. The sea-surface temperature (SST) at the point where Piper's intensity peaked was approximately 25°C (Figure 3-14-5). Piper remained a well-defined TC with an intensity of 60 kt (31 m/sec) near 40°N, (Figure 3-20-4), even though SSTs were only 20°C.

IV. IMPACT

No reports of damage or injury were received at the JTWC.

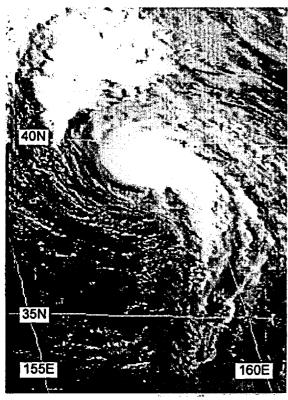


Figure 3-20-4 Piper's small well-defined CDO begins its northward acceleration over cooler SST and toward a frontal cloud band (252131Z August visible GMS imagery).

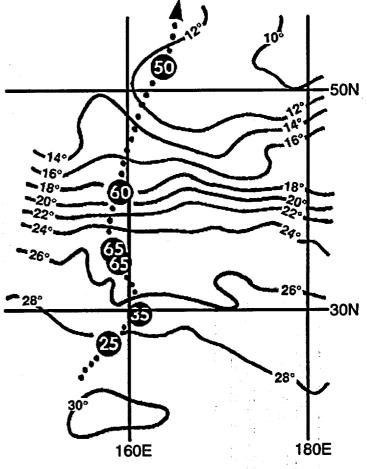
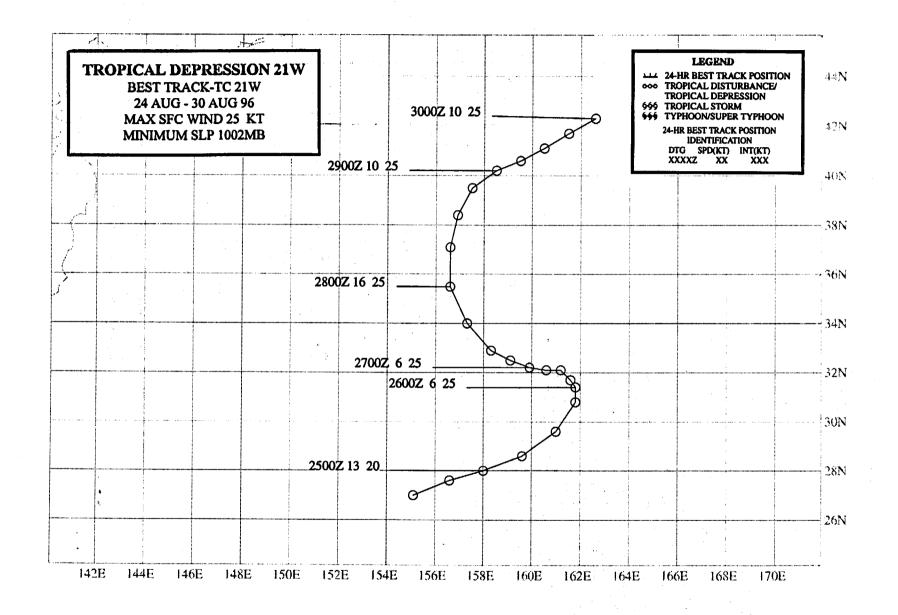


Figure 3-20-5 Piper reaches typhoon intensity at an unusually high latitude, and over relatively cool SST. (SST contours are based upon 220000Z August FNMOC analysis).



TROPICAL DEPRESSION 21W

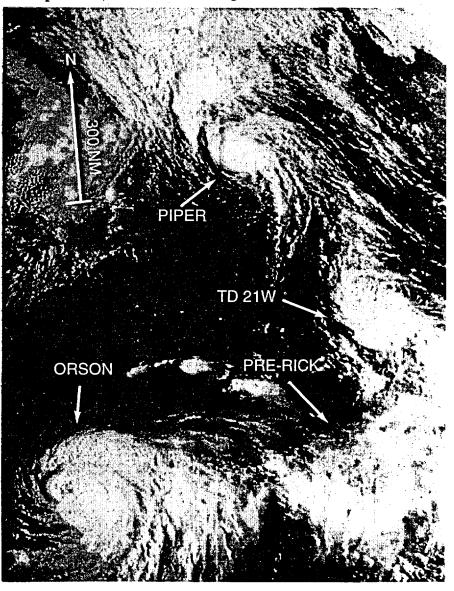
Forming at the end of a northward-displaced monsoon trough, Tropical Depression 21W followed an "S"-shaped poleward-oriented track close on the heels of Typhoon Piper (20W) (Figure 3-21-1). Emerging rather quickly from the end of the monsoon trough, the tropical disturbance that became TD 21W was never mentioned on the Significant Tropical Weather Advisory, but rather, a Tropical Cyclone Formation Alert (TCFA) was issued at 252330Z August followed immediately by a warning valid at 260000Z. Remarks on the TCFA included:

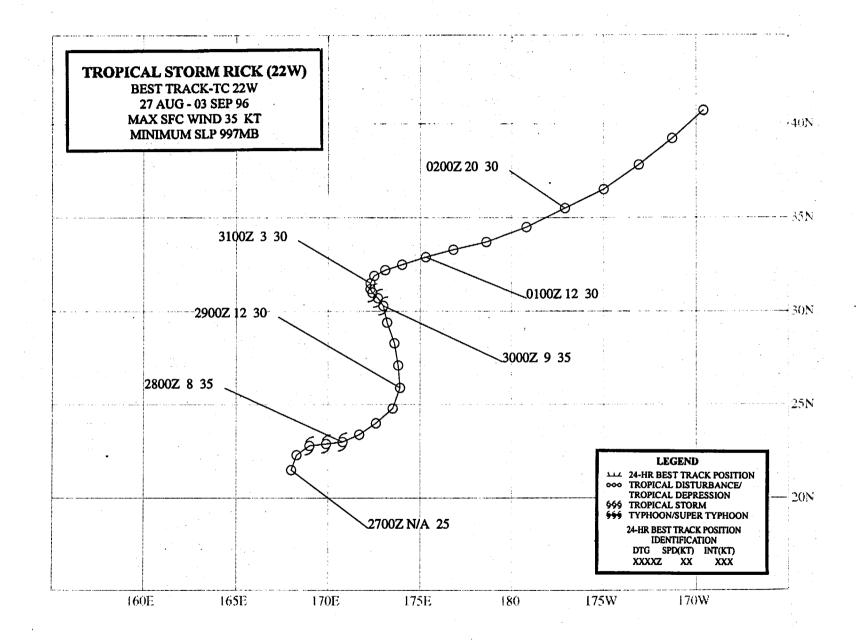
"A tropical disturbance has developed within the monsoon trough, between Tropical Storm Piper (20W) and Typhoon Orson (19W). Upper-level data favors continued development. At this time, the system is expected to follow Piper (20W) up the midlatitude trough axis. A warning message is forthcoming."

Soon after the first warning, TD 21W lost most of its central deep convection and it failed to mature (although a well-defined LLCC persisted). The final warning was issued valid at 271200Z,

when it was thought that the LLCC of TD 21W was going to dissipate over water. The LLCC did not dissipate, however, and in post analysis it was carried as a 25 kt (13 m/sec) tropical depression for another 60 hours as it recurved on the final leg of its "S"-shaped track.

Figure 3-21-1 Tropical Depression 21W is forming at the end of the monsoon trough. With Piper (20W) to its north, and Orson (19W) to its southwest, TD 21W is set to move north and leave a vacancy at the end of the trough to be filled by yet another TC, Rick (22W) (252224Z August visible GMS imagery).





TROPICAL STORM RICK (22W)

I. HIGHLIGHTS

Rick formed at a high latitude at the end of a northward-displaced monsoon trough. The first warning was issued without a prior Tropical Cyclone Formation Alert when scatterometer data indicated the well-defined low-level circulation possessed winds of at least 30 kt (15 m/sec).

II. TRACK AND INTENSITY

During the last week of August, the axis of the monsoon trough was displaced well to the north of its normal location. Anchored at 25°N by the slow-moving Orson (19W), the axis of the monsoon trough extended east-northeastward toward the international date line. Prior to Rick's formation, two other TCs — Typhoon Piper (20W) and Tropical Depression 21W — formed at the end of this monsoon trough and moved on poleward-oriented "S"-shaped tracks.

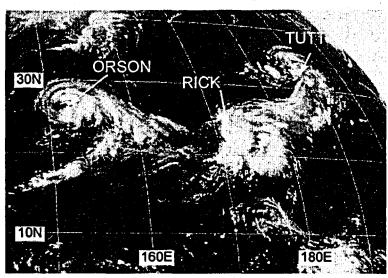


Figure 3-22-1 The tropical disturbance that became Rick is located between Orson (19W) and a TUTT cell. Scatterometer data at this time showed that it was already at tropical-storm intensity, and the final best track was adjusted accordingly (272130Z August infrared GMS imagery).

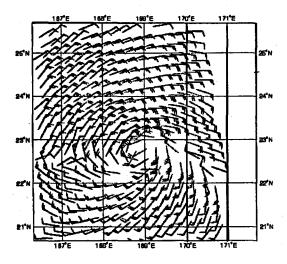


Figure 3-22-2 A well-defined LLCC with maximum winds of 30 kt accompanies "Rick's" cloud system at the time of the image in figure 3-22-1 (272110Z August ERS-2 scatterometer-derived winds).

The tropical disturbance which became Rick was located between Orson (19W) and a well-defined TUTT cell (Figure 3-22-1). This disturbance was first mentioned on the 260600Z August Significant Tropical Weather Advisory when synoptic data indicated that it was accompanied by a weak LLCC. When a scatterometer pass at 271121Z (Figure 3-22-2) revealed that a well-defined LLCC (with maximum winds of 30 kt) accompanied the poorly-organized cloud system shown in Figure 3-22-1, the JTWC issued the first warning (valid at 280000Z) on Tropical Depression (TD) 22W. In post analysis, the scatterometer pass was used to upgrade TD 22W to tropical-storm intensity at an earlier time than upgraded while in warning status.

Initially moving northeastward along the axis of the monsoon trough, TD 22W turned to the north when it approached a blocking high. After crossing 30°N, TD 22W slowed and its cloud pattern became better defined (Figure 3-22-3, see also Figure 3-21-1 in the summary of TD 21W). Better cloud organization and satellite-based microwave data (SSM/I) indicating 35 kt (18 m/sec)

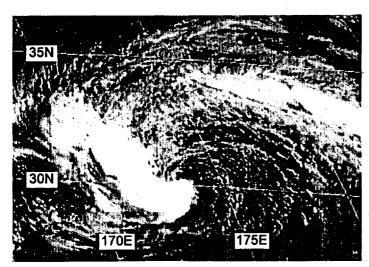


Figure 3-22-3 The primary band of deep convection coils around the western side of Rick's partially exposed LLCC (292131Z August visible GMS imagery).

prompted the JTWC to upgrade TD 22W to Tropical Storm Rick on the warning valid at 300000Z. On the warning valid at 301200Z, the system was downgraded to a tropical depression when the amount of its central deep convection decreased.

On 31 August, the system entered the accelerating westerlies regime north of the subtropical ridge. While Rick was moving east-northeastward at the base of an advancing frontal cloud band, its final warning was issued valid at 311200Z. The remnants of Rick continued to sweep northeastward within the frontal cloud band. The final best track carries the system across the international date line and north of 40°N.

III. DISCUSSION

a. High latitude of formation

Tropical cyclogenesis (TC genesis) is relatively rare east of 160°E and north of 20°N in the WNP. There are two synoptic conditions that lead to most of the TC genesis there: (1) TUTT-induced TC genesis, and (2) TC genesis that occurs when the monsoon trough has penetrated unusually far to the north and east. In Rick's case, the monsoon trough had migrated to an unusually high latitude, and the disturbance that became Rick formed at the eastern end of this trough. There was also a large well-defined TUTT cell northeast of this disturbance (Figure 3-22-1), but its role (if any) in Rick's development is not clear.

b. Scatterometer data

The first warning on Rick was based upon scatterometer data from the European Remote Sensing Satellite-2 (ERS-2) (Figure 3-22-2). The JTWC has access to scatterometer wind data, and has used it to help determine the position, intensity and wind distribution of TCs for nearly one and a half years. Some drawbacks of the scatterometer data are its small swath width, 180° directional ambiguity, relatively coarse resolution, limitations on the wind speeds it can accurately detect, and a low-speed bias.

The scatterometer pass which prompted the first warning on TD 22W (Figure 3-22-2) contains many 25-kt (13-m/sec) wind reports, with a maximum report of 30 kt (15 m/sec) just east of the system center. In real time, this was used to support a warning intensity of 30 kt, but, in post analysis was used to upgrade TD 22W to tropical-storm intensity at an earlier time. When compared with buoys and ship reports, the scatterometer winds generally have a low-speed bias (Quilfen, 1992; Laing, 1994; and Laing and Brenstrum, 1996). Laing and Brenstrum (1996) showed that the ERS-1 winds had a mean low-speed bias of about 4 kt (2 m/sec) when compared with the winds recorded on a New Zealand research ship (Figure 3-22-4). The magnitude of this bias increases with increasing wind speed. The low-speed bias increases to near 6 kt (3 m/sec) at wind speeds of 30 kt (15 m/sec). In operational practice, the JTWC treats a 30-kt scatterometer wind as representative of a 35-kt one-minute average 10-m wind. Hence, the 30-kt maximum scatterometer wind in Figure 3-22-2 was used in post analysis as grounds for upgrading the intensity of TD 22W from 30 kt to 35 kt (i.e., from a tropical depression to a tropical storm).

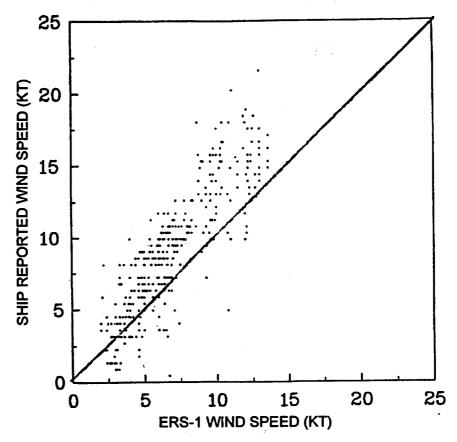
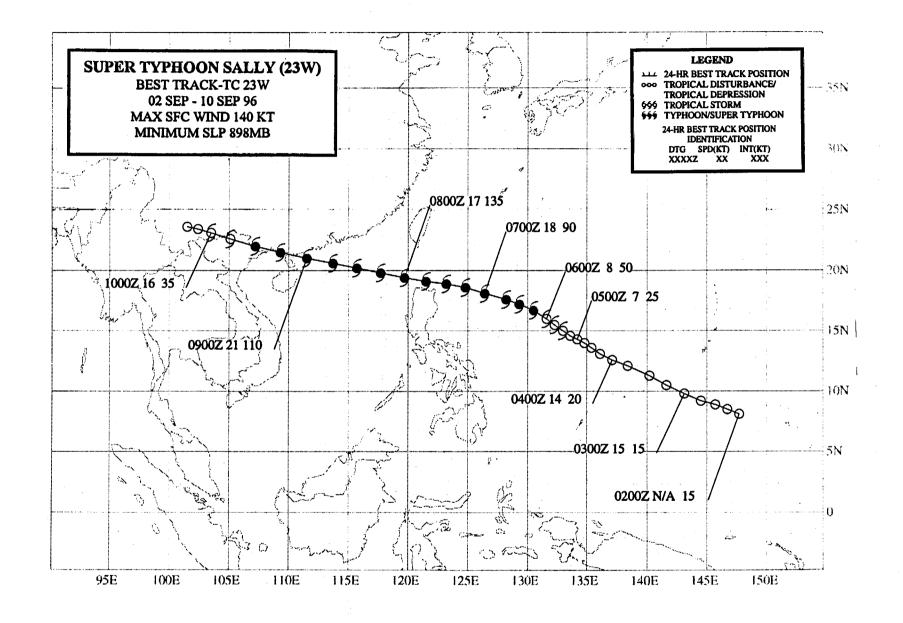


Figure 3-22-4 A comparison of the wind speeds recorded by the New Zealand research ship Tangaroa with wind speeds obtained from the ERS-1 scatterometer. That most of the points are above the 45° line indicate that the ship wind speeds are generally higher than those estimated by the scatterometer. (Figure adapted from Figure 2 of Laing and Brenstrum (1996).)

IV. IMPACT No reports of damage or injury were received at the JTWC.



SUPER TYPHOON SALLY (23W)

I. HIGHLIGHTS

As the long-lived Orson (19W) recurved at the beginning of September, the unusual monsoon flow pattern of August (See figure 3-13-4 in Kirk's summary) gave way to a pattern more in line with climatology: the maximum cloud zone and the axis of the monsoon trough became established from the Philippines east-southeastward into Micronesia. Sally was the first of five significant TCs to develop in this new monsoon flow pattern. Forming to the southwest of Guam, Sally moved on a relatively steady west-northwest straight-moving track. It became a super typhoon while moving through the Luzon Strait, and later, though weaker, it made landfall in southwestern China where it caused extensive damage and considerable loss of life.

II. TRACK AND INTENSITY

On the first day of September, Typhoon Orson (19W) was recurving to the east of Japan, and the deep tropics of the WNP were abnormally free of deep convection. Over the next two days, as Orson (19W) recurved into the midlatitudes, amounts of deep convection in the low latitudes of the WNP began to rapidly increase as a new monsoon trough was becoming established there. On 02 September, when amounts of deep convection in the low latitudes of the WNP began to increase, a tropical disturbance quickly consolidated near the island of Guam. It was first mentioned on the 020600Z Significant Tropical Weather Advisory, which described it as follows:

"An area of convection is located near 11N 145E. Satellite imagery and synoptic data indicate a broad area of convection surrounding an inverted trough in the trade wind flow. . . ."

Early on 04 September, synoptic data showed that a low-level cyclonic circulation had formed in the monsoon trough in association with this disturbance. Cirrus outflow was well organized into an anticyclonic pattern with a center of symmetry over the LLCC. This prompted the JTWC to issue a Tropical Cyclone Formation Alert (TCFA) at 032300Z September. The MCSs comprising this disturbance were growing and collapsing at the typical 06- to 12-hour MCS time scale, creating some difficulty for the satellite analysts to accurately locate the LLCC. The uncertain knowledge of the location of the LLCC led to a second TCFA at 042300Z in order to carry the alert beyond the expiration of the first, and to give JTWC forecasters some time to gather information for the first warning (which was in preparation when the first TCFA was about to expire). As expected, the second TCFA was quickly followed by the first warning on Tropical Depression (TD) 23W, valid at 050000Z, when morning visible satellite imagery allowed for a more accurate determination of the position of the LLCC and indicated an intensity of 25 kt (13 m/sec). From this time onward (until peak), intensification proceeded at a faster than normal rate (i.e., 1.5 T numbers per day versus the normal 1 T number per day). TD 23W was upgraded to Tropical Storm Sally on the warning valid at 051800Z. The system became a typhoon at 060600Z, and a super typhoon at approximately 071600Z. The peak intensity of 140 kt (72 m/sec) occurred at 071800Z (Figure 3-23-1) as the cyclone moved through the Luzon Strait. Moving west-northwestward at nearly 20 kt (37 km/hr), the typhoon crossed the northern reaches of the South China Sea (SCS) under the steering influence of a dominant subtropical ridge. The system weakened as it moved across the SCS, but it was still potent with an intensity of approximately 100 kt (51 m/sec) when it made landfall on the Luichow peninsula in southwestern China. The typhoon crossed the Luichow peninsula and then moved along the Chinese Gulf-of-Tonkin coastline. The system went inland for good just north of China's border with Vietnam. The final warning was issued, valid at 091200Z, as the weakening TC continued its trek inland across the far north of Vietnam and southwestern China.

III. DISCUSSION

Sally's digital Dvorak (DD) numbers: a pattern begins to emerge

During 1996, the hourly time series of the DD numbers was computed and archived for all typhoons (during 1995, hourly DD numbers were computed for some selected TCs, Ward, for example). The hourly time series of Sally's DD numbers (Figure 3-23-2) shows a characteristic pattern that appears to be typical of some of the other very intense typhoons of 1996 and 1995:

- 1) the DD time series rises more rapidly than the best-track intensity (which is based primarily upon the manual application of Dvorak's techniques);
 - 2) the DD time series peaks earlier than the best-track intensity;
- 3) the peak of the DD time series is approximately one-half of a T number higher that the best-track peak; and,
- 4) within 24 hours of the DD peak, there is a dramatic drop of the DD values of 2 or more T numbers, and then a recovery. Some or all of these behaviors are seen in the DD time series of Eve (07W), Dale (36W) and to a lesser extent Herb (10W) and Violet (26W).

These specific characteristic behaviors of the DD time series are closely tied to the evolution of the character of the eye. As TCs approach their peak intensity, their eyes are usually small and well defined. Why the DD numbers rise more quickly and peak earlier and higher than the best track has not been determined. The dramatic fall of the DD time series following the peak can usually be linked to the formation of concentric wall clouds. The DD numbers recover from the dramatic fall after the inner wall cloud collapses and a new larger eye is established.

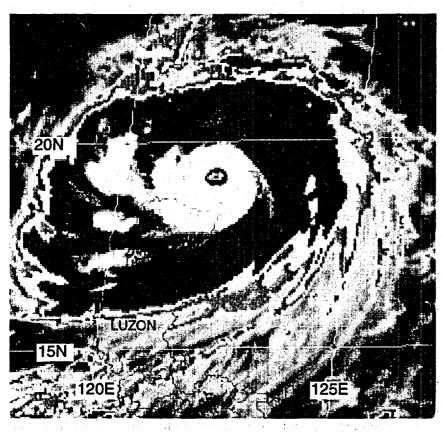


Figure 3-23-1 Sally shortly before reaching its peak intensity of 140 kt (72 m/sec) (071631Z September enhanced infrared GMS imagery). Enhancement curve is "MB".

IV. IMPACT

Sally was catastrophic in southern China. At least 114 people were reported killed with another 110 missing. The city of Zhanjiang on the east coast of the Luichow peninsula was one of the hardest hit. Here, 79 people were reported killed. Almost all trees in this city and its suburbs were reported to have been uprooted by high winds. Economic losses were described as the worst since 1954. Combined losses in the cities of Zhanjiang and Maoming were estimated at US \$1.5 billion.

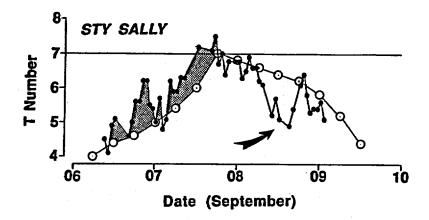
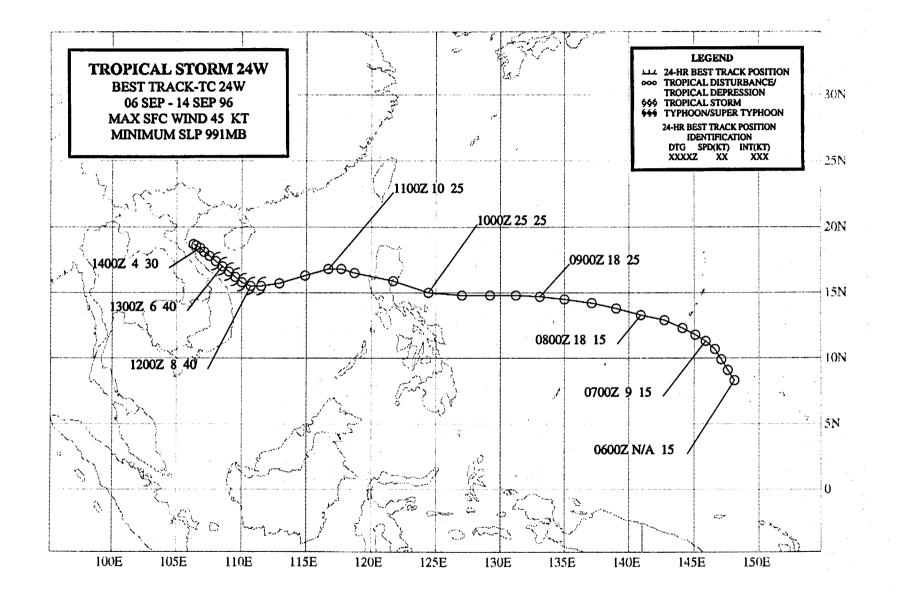


Figure 3-23-2 The time series of Sally's hourly DD numbers (small black dots connected by thin solid line). For comparison, the final best track intensity at six-hour intervals (converted to a T number) is superimposed (open circles connected by thin solid line). Shaded regions indicate that the DD number is higher than the best-track intensity. The arrow points to the relative minimum in the DD time series which occurred approximately 24 hours after the peak in the DD numbers.



TROPICAL STORM 24W

As the long-lived Orson (19W) recurved at the beginning of September, the unusual monsoon flow pattern of August (see figure 3-13-4 in Kirk's summary) gave way to a pattern more in line with climatology: the maximum cloud zone and the axis of the monsoon trough extended from the Philippines east-southeastward into Micronesia. Tropical Storm 24W was the second of five significant TCs to form in this trough.

On 07 September, an area of deep convection began to consolidate into a discrete tropical disturbance located near Guam. First mentioned on the 071600Z September Significant Tropical Weather Advisory, this disturbance became a large monsoon depression in the Philippine Sea by the morning of 09 September (Figure 3-24-1). Although the definition of a monsoon depression includes large size, the disturbance which became Tropical Storm 24W was exceptionally large with its loosely organized ensemble of MCSs stretching nearly 25° (1500 nm; 2800 km) from the Philippines to Guam. Based upon consolidation of deep convection into a smaller area, the JTWC issued a Tropical Cyclone Formation Alert valid at 090500Z. Remarks on this alert included:

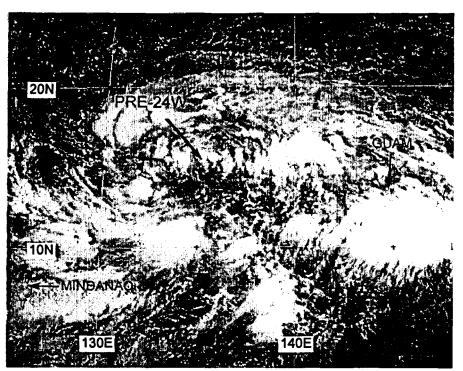


Figure 3-24-1 The cyclonic circulation center which became Tropical Storm 24W consolidated within a large monsoon depression. Another area of deep convection near Guam later detached from the monsoon depression and became Violet (26W) (082224Z September visible GMS imagery).

"Synoptic data and visible satellite imagery reveal the presence of a broad monsoon depression with the dominant circulation center [located near 15°N; 133°E]. Convection associated with this disturbance is limited to a broad ring approximately 600 nm in diameter. Maximum sustained winds are limited to the convective regions on the periphery of this system...."

The first warning on Tropical Depression (TD) 24W was issued valid an hour later at 090600Z based upon ship reports of 20 to 25 kt (10-13 m/sec) in the convective regions approximately 120 nm (220 km) to the north and southwest of the LLCC.

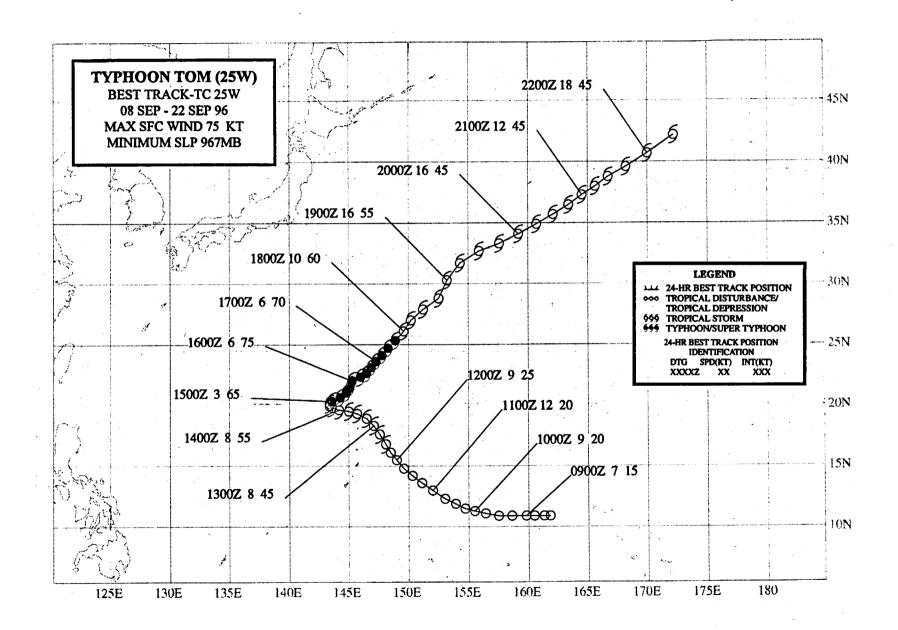
The monsoon depression which became TD 24W had a complex evolution. Not only

did it lead to the formation of TD 24W, but another cyclonic circulation associated with it became Violet (26W). This complexity is described in remarks on the 100600Z Significant Tropical Weather Advisory:

"An area of convection [pre-Violet] is located near 13N 140E. Satellite imagery and synoptic data indicate this is a convective region formerly associated with Tropical Depression 24W that has separated from TD 24W and remained quasi-stationary as TD 24W moves west. . . . "

On 10 September, TD 24W crossed Luzon and entered the South China Sea. During the following three days it traversed the SCS, moved into the Gulf of Tonkin on 14 September, and weakened. The final warning, valid at 141200Z, was issued when the system dissipated near the coast of northern Vietnam.

TD 24W was upgraded to a tropical storm in postanalysis based on synoptic data which indicated sustained winds in the system reached a peak of 45 kt (23 m/sec) at 120600Z.



TYPHOON TOM (25W)

I. HIGHLIGHTS

Tom was the third of five significant TCs to form in the monsoon trough. At one point, Tom, Violet (26W), Willie (27W) and a subtropical (ST) low existed simultaneously along the trough axis (Figure 3-25-1a, b). Due to the relative motions of these TCs (and the ST low), the trough axis became reverse oriented. Both Tom and Violet (26W) were large TCs. Tom also had an unusual structure featuring a "pin-hole" eye in a small central cloud mass surrounded by extensive peripheral rain bands within a large outer wind field. Tom is a good case for the argument that the core of a TC is largely independent of its outer structure.

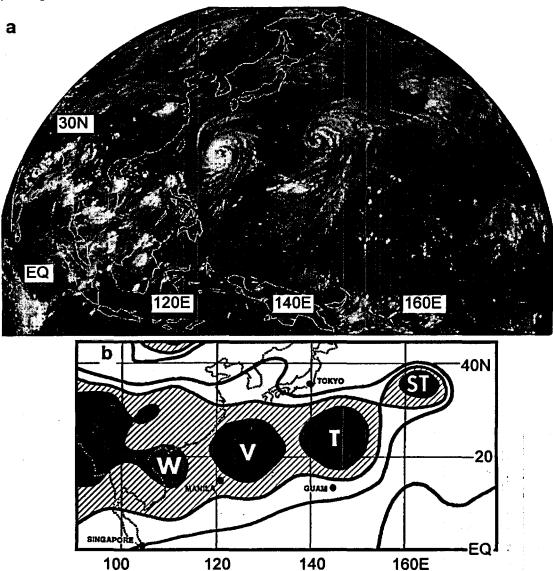


Figure 3-25-1 From west-to-east, TCs Willie (27W), Violet (26W), Tom (25W), and a subtropical low lie along the axis of a reverse-oriented monsoon trough. (a) 171231Z September infrared GMS imagery. (b) Sea-level pressure analysis (outer contour is 1010 mb, cross-hatched areas are between 1004 and 1008 mb, and black regions are less than 1004 mb) (Illustration based upon NOGAPS 170000Z September SLP analysis).

II. TRACK AND INTENSITY

During the second week of September, the cloudiness associated with the monsoon trough began to consolidate into discrete areas of persistent convection. A low-level cyclonic circulation located to the southwest of the easternmost of these areas became Tom, and was first mentioned on the 080600Z September Significant Tropical Weather Advisory. Embedded in an ensemble of poorly organized MCSs, the weak surface low drifted westward for two days with little development. Then, early on 11 September, the convection associated with the surface circulation became better organized, prompting the JTWC to issue a Tropical Cyclone Formation Alert valid at 102030Z. Moving toward the northwest, the deep convection associated with the system began to consolidate. Based on satellite intensity estimates of 25 kt (13 m/sec) and synoptic conditions deemed favorable for further development (e.g., good outflow in all quadrants as revealed by water-vapor derived

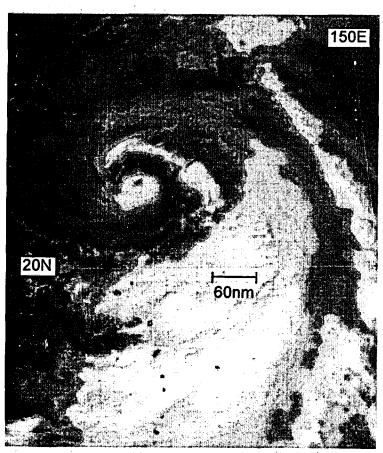


Figure 3-25-2 Tom reaches its peak intensity of 75 kt (39 m/sec). Note the small size of the eye and core cloud features with respect to the peripheral cloud features (160131Z September visible GMS imagery).

winds), the first warning on Tropical Depression (TD) 25W was issued valid at 111800Z. Moving slowly toward the northwest, TD 25W became Tropical Storm Tom on the warning valid at 121200Z. Tom became a typhoon at 150000Z. Also at 150000Z, Tom began to move slowly toward the northeast, almost at the same time as Typhoon Violet (26W) (located approximately 1100 nm (2050 km) to Tom's west-southwest) did likewise. The turn to the northeast of Tom and Violet (26W) was associated with the monsoon trough acquiring a reverse orientation (as mentioned in the 150000Z Prognostic Reasoning for Typhoon Tom).

A common behavior of typhoons moving northeastward in a reverse-oriented monsoon trough, Tom continued to intensify while moving northeastward at 6 kt (11 km/hr), reached its peak of 75 kt (39 m/sec) at 151800Z (Figure 3-25-2), and maintained that intensity until after 161800Z. Slowly gaining forward speed, Tom gradually weakened as it moved toward the northeast. It eventually became a large extratropical low, but not before undergoing a lengthy period of

extratropical transition for which the JTWC satellite forecasters instituted a new intensity estimation technique developed by Miller and Lander (1996) (see the discussion). Deemed to have nearly completed its extratropical transition, the final warning was issued valid at 200600Z.

III. DISCUSSION

a. Tom's behavior in a reverse-oriented monsoon trough

When the monsoon trough acquires a reverse orientation, a ridge of high pressure often builds to its south creating steering flow which causes TCs associated with the reverse-oriented monsoon trough (RMT) to move on north-oriented tracks. Premature eastward motion at low latitude is a common behavior of TCs located along the axis of an RMT. Such eastward turns at lowlatitude are not considered "classic recurvature" because the TC is being steered by dominating monsoonal flow rather than by entry into the midlatitude westerlies. Often, the subtropical ridge is still in-place to the north of the RMT, and the TC is seen to undergo "S" motion (i.e., making a turn back to the northwest while moving through the subtropical ridge and entering the midlatitude westerlies). Another characteristic behavior of TCs while embedded in an RMT is intensification of the TC while moving on a track with an eastward component of motion (such was the case with Tom). The monsoon trough within which Tom was embedded, became reverse oriented by virtue of the relative motion of Tom and Violet (26W) (Figure 3-25-3). Both of these TCs moved on similarly shaped tracks, however, there was a gradual cyclonic rotation of the two about their centroid so that Tom, once east-southeast of Violet, moved to the east-northeast of Violet. For further information regarding the behavior of TCs associated with an RMT see Lander (1996) and the discussion of reverse-trough formation and poleward-oriented motion in Carr and Elsberry (1994).

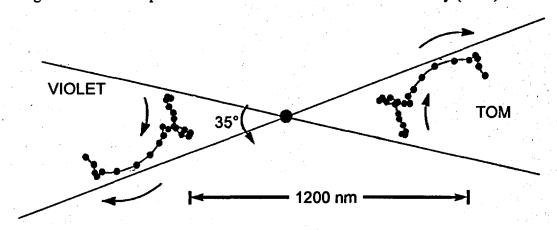


Figure 3-25-3 Centroid relative motion of Tom and Violet (26W). Dots are at 12-hour intervals beginning at 100000Z and ending at 220000Z.

b. Unusual cloud signature

When Tom reached its peak intensity of 75 kt (39 m/sec), it had an unusual structure featuring a "pin-hole" eye in a small central cloud mass surrounded by extensive peripheral rain bands within a large outer wind field (Figure 3-25-2). Tom is a good case for the argument that the core of a TC is largely independent of its outer structure. Take away the peripheral rain bands and the deep convection extending southwestward within the monsoon flow and Tom's small core is indistinguishable from a small TC with a small eye. By contrast, Typhoon Violet (26W) (located to the west of Tom) had a size similar to Tom, and yet the structure of its core was quite different: Violet's eye began small, but then expanded to a diameter on the order of 75 nm (140 km). The distinction between the TC core and its outer structure also has relevance to the evolution of monsoon depressions to conventional TCs (i.e., one of Dvorak's four data types). It is not clear by what pathway monsoon depressions become conventional TCs.

c. On the use of scatterometry to assess the wind distribution of large TCs

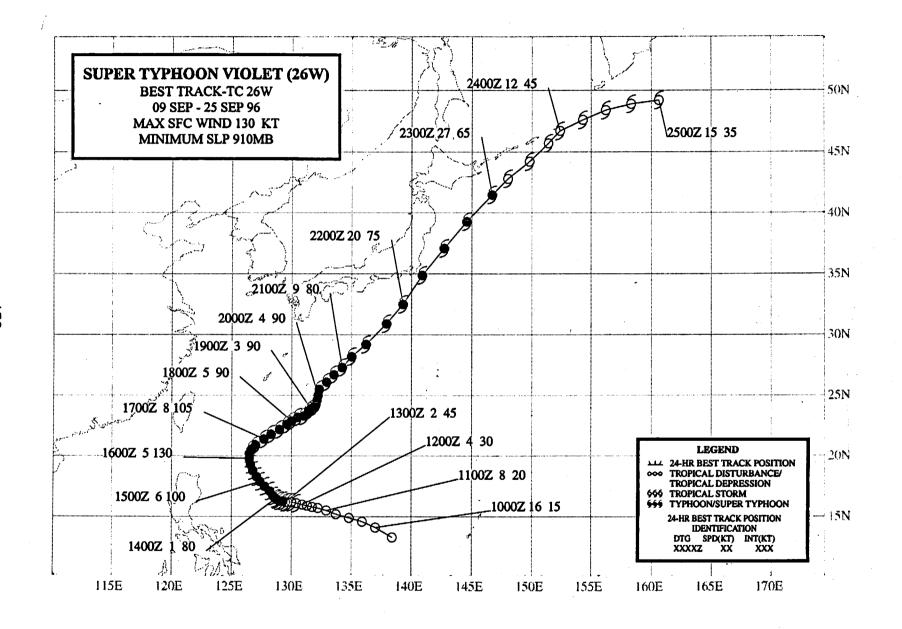
One of the limitations of the ERS-2 scatterometer data is its narrow swath width (approximately 7 degrees of great circle arc). When available, JTWC uses scatterometer data to evaluate the outer wind distribution of TCs (i.e., the radial extent of gales). For small TCs, the scatterometer often misses the TC for several passes, and even misses the peripheral gale area. For larger TCs like Tom, almost every scatterometer pass in the region of the TC samples a portion of its gale area, and thus, by piecing together the several hits on portions of the gale area, a picture of the wind distribution emerges —the problem of narrow swath width has less impact.

d. First use of the "XT" technique

A review of the 1994 and 1995 WNP TC data revealed the intensity estimates of a significant number of TCs that recurved and moved out of the tropics were underestimated by the TC satellite reconnaissance network which used Dvorak's techniques to determine intensity. Intensity estimates for Dan (06W) as it was recurving illustrate the problem (see Dan's (06W) summary). In order to address the problem of underestimating the intensity of TCs undergoing extratropical transition, satellite forecasters at the JTWC in conjunction with ONR-supported researchers at the University of Guam devised a technique (Miller and Lander, 1996) for estimating the intensity of TCs undergoing extratropical transition (see Dan's summary for more details on the technique). This technique yields XT (for extratropical transition) numbers that equate to wind speeds identical to Dvorak's T numbers of the same magnitude. The first application of the technique was on Tom as it was becoming extratropical. The JTWC satellite fix at 192330Z represented the first assignment ever of an XT number to a TC. The XT number determined for Tom at this time was XT 3.0. Other agencies using Dvorak's T numbers, or Hebert and Poteat's ST numbers were up to two T numbers lower than the JTWC intensity estimate. Scatterometer data and other synoptic data at the time supported the JTWC intensity estimate of XT 3.0 (i.e., 45 kt (23 m/sec)).

IV. IMPACT

No reports of damage or injury were received at the JTWC.



SUPER TYPHOON VIOLET (26W)

I. HIGHLIGHTS

As the long-lived Orson (19W) recurved at the beginning of September, the unusual monsoon flow pattern of August (See Figure 3-13-4 in Kirk's summary) gave way to a pattern more in line with climatology: the maximum cloud zone and the axis of the monsoon trough extended from the Philippines east-southeastward into Micronesia. Violet was the fourth of five significant TCs to form in this trough. At one point, Tom (25W), Violet, Willie (27W) and a subtropical (ST) low existed simultaneously along the trough axis (see Figure 3-25-1a, b in Tom's (25W) summary). Due to the relative motions of these TCs (and the ST low), the trough axis became reverse oriented. Violet was one of three TCs during 1996 which acquired a very large eye — the other two were Kirk (13W) and Orson (19W). Passing just off the southeastern tip of the Japanese main island of Honshu, Violet was responsible for extensive damage and loss of life.

II. TRACK AND INTENSITY

On 10 September, an area of deep convection began to consolidate into a discrete tropical disturbance located between the Philippines and Guam. The early stages of this tropical disturbance were somewhat complicated as noted in the remarks on the 100600Z Significant Tropical Weather Advisory: "An area of convection is located near 13N 140E. Satellite imagery and synoptic data indicate this is a convective region formerly associated with Tropical Depression 24W that has separated from TD 24W and remained quasi-stationary as TD 24W moves west. . . ." On 11 September, the disturbance became better organized, and remarks on the 110600Z Significant Tropical Weather Advisory included:

"The area of convection previously located near 13N 140E [has moved west].... Synoptic data indicate this convective region lies near a broad cyclonic circulation along the monsoon trough...."

Further consolidation of the deep convection and rapid improvements in the organization of the convection and of its outflow cirrus prompted JTWC to issue a Tropical Cyclone Formation Alert at 111100Z September, followed by the first warning on Tropical Depression (TD) 26W, valid at 111800Z. This is the same valid time for the first warning on the tropical depression that became Tom (25W) — a TC located approximately 1000 nm (1900 km) to the east-southeast of TD 26W. At the time of the first warning on TD 26W, NOGAPS was indicating TD 25W (Tom) would become the dominant system and engulf the smaller circulation of TD 26W. The official forecast reflected the dynamic guidance and dissipated TD 26W as a significant tropical cyclone in 36 hours. The dynamic guidance was in error, and TD 26W intensified and eventually became a large intense TC with a size comparable to that of Tom (25W) (see Figure 3-25-1b in Tom's summary). TD 26W was upgraded to Tropical Storm Violet on the warning valid at 121800Z. The system became a typhoon at 130600Z and reached its peak intensity of 130 kt (67 m/sec) at 160000Z (Figure 3-26-1).

After becoming a typhoon, Violet turned and began to move very slowly toward the northwest. When the typhoon reached its peak intensity at 160000Z, it began to track slowly toward the northeast in tandem with Tom (25W) (located approximately 1100 nm (2050 km) to Violet's east-northeast). The turn to the northeast of Violet and of Tom (25W) was associated with the monsoon trough acquiring a reverse orientation. Whereas Tom continued to intensify while moving northeastward, Violet began to weaken. As it weakened, its eye became very large (Figure 3-26-2) (see the discussion). Slowly gaining forward speed, Violet continued to weaken as it moved toward the

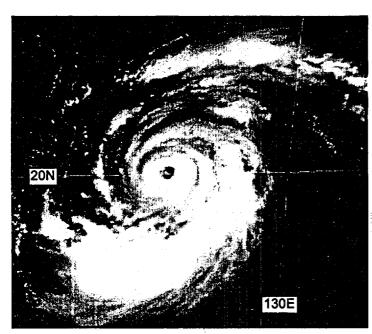


Figure 3-26-1 Violet at its peak intensity of 130 kt (67 m/sec) (160131Z September visible GMS imagery).

northeast. Its large eye passed just offshore to the east of the Tokyo area. High winds and heavy rains caused damage and loss of life in southeastern Japan (see the Impact section). The final warning was issued valid at 230000Z as the typhoon continued on a northeastward track toward the eastern end of the Kuril Island chain where it became an extratropical low.

III. DISCUSSION

a. Violet's behavior in a reverse-oriented monsoon trough

The monsoon trough within which Violet was embedded, became reverse oriented by virtue of the relative motion of Tom (25W) and Violet (see Figure 3-25-3 in Tom's summary). Both of these TCs moved on similarly shaped tracks, however,

there was a gradual cyclonic rotation of the two about their centroid so that Tom, once east-south-east of Violet, moved so as to be located to the east-northeast of Violet. For more details on the characteristics of TC motion in a reverse-oriented monsoon trough see Tom's (25W) summary.

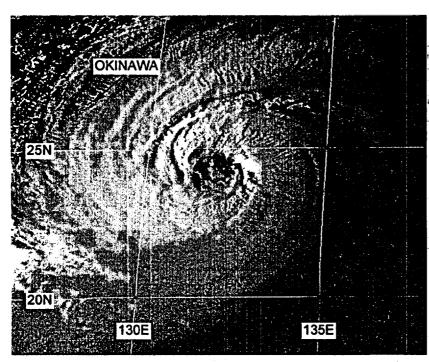


Figure 3-26-2 Violet was one of three WNP TCs during 1996 which acquired a very large eye with a maximum satellite-observed diameter greater than 75 nm (140 km) (190831Z September visible GMS imagery).

b. Very large eye

Violet was one of three TCs during 1996 — the other two were Kirk (13W) and Orson (19W) that acquired very large eyes. Violet's eye evolved greatly during its life: it was at times a banding eye, a large ragged eye, an eye with concentric wall clouds, a small well-defined eye, and a very large eye. The changes in the character of Violet's eye were reflected in fluctuations of Violet's digital Dvorak (DD) numbers (Figure 3-26-3). From 172330Z to 201130Z Violet's satelliteobserved eye diameter exceeded 45 nm (85 km) (Figure 3-26-4). From 190450Z to 192030Z the eye diameter ranged from 62 to 79 nm (115 to 145 km) (Table 3-26-1).

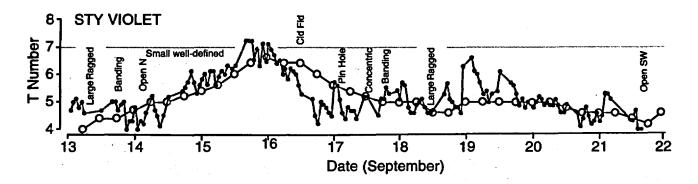


Figure 3-26-3 Violet's DD time series for the period 130130Z September through 211830Z September. Small black dots are the hourly DD values, open circles are the best track intensity (converted to a T number). Comments on the structure of the eye are included.

Table 3-26-1 Eye diameter of Violet from satellite during its period of very large eye size.

		and the second second
		Satellite-derived
DTG(Z)	T Number	eye diameter (nm)
172330	4.0	52
180230		45
180330		65
180430		42
180501*	4.0	58
180511*	4.0	64
182030		46
182111	4.5	55
182330	5.0	63
190230		59
190450	4.5	76
190530	5.0	62
190828	4.5	72
190830		78 .
191130	5.0	75
191630	·	79
191730	5.0	78
192030		71
192330	4.5	59
200230		49
200430	4.5	51
200830		64
201130	4.0	72
1		

^{*} These fixes are from different agencies using the same NOAA-14 pass.

c. Gravity waves

When Violet passed through the eastern part of the Kuril Island chain on 24 September, the rugged high islands produced a spectacular display of gravity waves in the low and middle cloud field (Figure 3-26-5). Such displays of terrain-induced gravity waves are commonly observed in the flow of typhoons which are becoming extratropical. Stabilization of the lower atmosphere by ocean chilling sets up conditions favorable for these gravity waves. In the deep tropics (e.g., over the islands of the Philippines), terrain-induced gravity waves in the circulation of a TC are far less common.

IV. IMPACT

Violet was responsible for killing seven people and injuring 44 others in southeastern Japan. Based on radar and satellite data, the center of Violet's large ragged eye passed approximately 80 nm (150 km) to the east-southeast of the Tokyo metropolitan area, and about 30 nm (55 km) east of the coastal cities of Tateyama and Choshi in Chiba prefecture. The western wall cloud passed over Tokyo and nearby areas, dumping 10.4 inches (265 mm) of rain in 24 hours on Tokyo's main business district (the third-largest 24-hour rainfall recorded there since 1876), and producing wind gusts to near 100 kt (51 m/sec) in exposed coastal areas. Tateyama (on the

southern tip of Chiba prefecture) recorded a peak gust to 106 kt (55 m/sec) and a minimum SLP of 969 mb. No significant damage occurred at Fleet Activities Yokosuka, although numerous trees were uprooted or blown down and fencing along a sea wall was torn down due to wave action.

Figure 3-26-4 A close-up view of Violet's very large eye. The relatively clear region in the eye has a diameter of approximately 60 nm in this image (190038Z September visible DMSP imagery).

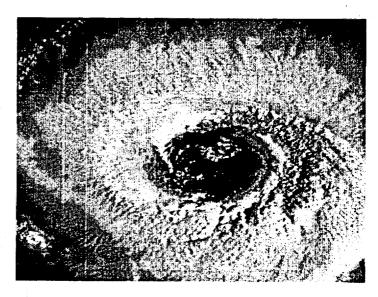
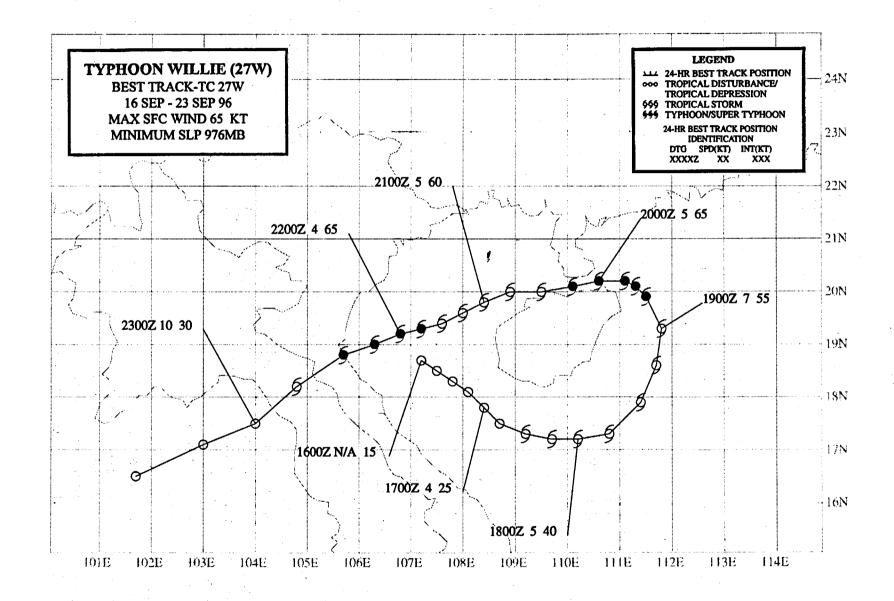




Figure 3-26-5 A multitude of gravity waves is apparent in the low and middle clouds of Violet as the system moves northeastward over the Kuril Islands (240332Z September visible GMS imagery).



TYPHOON WILLIE (27W)

I. HIGHLIGHTS

Never more than 90 nm (170 km) from shore, Willie circumnavigated Hainan Island while undergoing a counter-clockwise loop. Willie was a small TC, and was part of a three-TC outbreak along the monsoon trough, with the larger TCs Tom (25W) and Violet (26W) to its northeast.

II. TRACK AND INTENSITY

On 17 August, the axis of the monsoon trough stretched from Bangladesh to the Gulf of Tonkin, and from there into the WNP where the large typhoons Tom (25W) and Violet (26W) and a subtropical low had formed along it (see Figure 3-25-1a, b in Tom's (25W) summary). The small area of deep convection that became Willie was first mentioned on the 170600Z September Significant Tropical Weather Advisory based on its persistence near a low-level cyclonic circulation located to the southwest of Hainan Island. The area of deep convection moved to the east-southeast and became better organized, prompting the JTWC to issue a TCFA at 171130Z followed by the first

warning, valid at 171800Z, on Tropical Depression (TD) 27W. Six hours later, TD 27W was upgraded to Tropical Storm Willie based on several data sources:

- 1) a 171000Z report (received later at the JTWC) of 35 kt (18m/sec) sustained wind from the M/V GECO Emerald (a ship servicing the oil rigs south of Hainan);
- 2) a scatterometer pass at 171521Z supporting 35 kt one-minute sustained wind near the LLCC; and,
- 3) a significant improvement in convective organization.

During the afternoon of 19 August Willie acquired a ragged eye and became a typhoon (Figure 3-27-1). Willie maintained a peak intensity of 65 kt (33 m/sec) for 24 hours as it rounded the northeastern end of

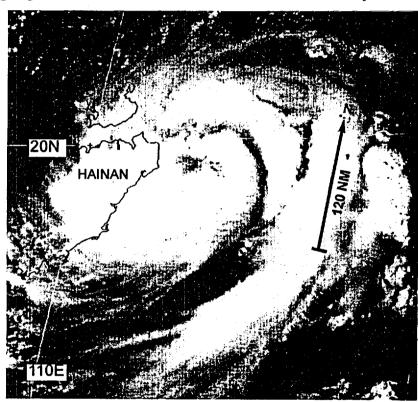


Figure 3-27-1 Willie becomes a typhoon (190531Z September visible GMS imagery).

Hainan. The system weakened slightly after passing through the narrow Hainan Strait, but became a minimal typhoon once again as it crossed the Gulf of Tonkin on a west-southwest track. As a minimal typhoon, Willie made landfall at approximately 221200Z in northern Vietnam near Vinh. Continuing on a southwestward track it crossed Laos into Thailand. The final warning, valid at 230000Z, was issued as the weakening system moved into northeastern Thailand and dissipated.

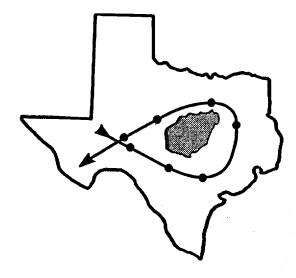


Figure 3-27-2 Willie's counter-clockwise loop fits comfortably within the boundaries of the State of Texas. Hainan Island (shaded) is superimposed. Dots show Willie's position at 24-hour intervals.

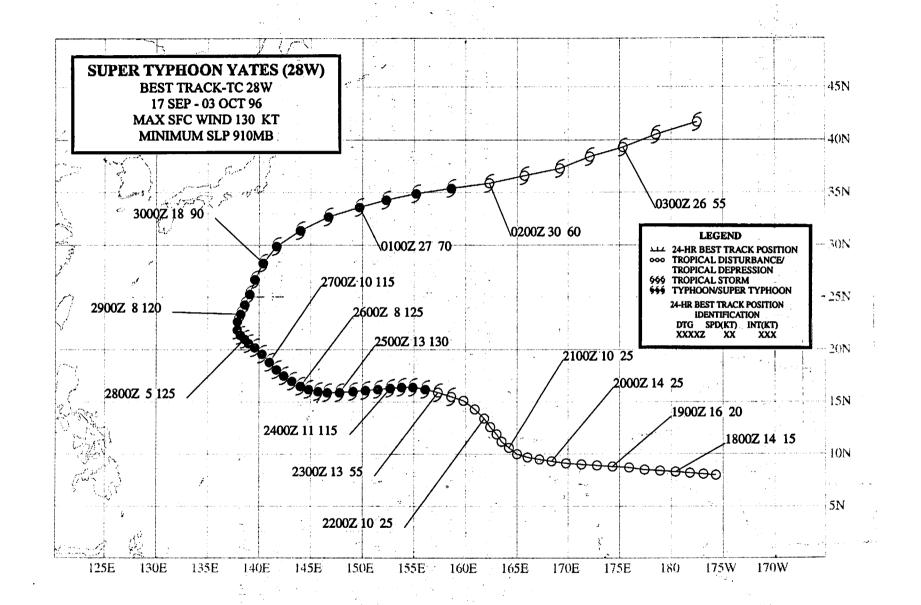
III. DISCUSSION

Unusual motion

Willie circumnavigated Hainan Island while undergoing a counter-clockwise loop. The dimensions of the oval-shaped loop were 300 nm by 180 nm (550 km by 330 km) which would fit comfortably within the boundaries of the State of Texas (Figure 3-27-2). The eastward motion of Willie during the first portion of its track is consistent with its position at the southwestern end of a reverse-oriented monsoon trough with typhoons Tom (25W) and Violet (26W) located further to the east-northeast along the trough axis. Initially steered eastward by deep monsoon flow along the trough axis, Willie turned toward the north and then toward the west, as Tom (25W) and Violet (26W) exited the tropics and a ridge gradually built to the north and east of Willie.

IV. IMPACT

At least 38 people were reported killed, dozens injured and 96 missing on Hainan Island. Willie smashed homes, washed away fishing boats and dumped up to 16 inches (400 mm) of rain on areas of this island province. Most of the deaths were attributed to flooding. No reports of damage or injuries in Vietnam were received at the JTWC.



SUPER TYPHOON YATES (28W)

I. HIGHLIGHTS

While passing between Saipan and Anatahan (two islands in the Northern Marianas), Yates was observed with Guam's NEXRAD. Although Yates became a super typhoon, its surface wind field was relatively compact, and it possessed a very small satellite-observed eye for much of its life. Yates and Zane (29W) developed in the same monsoon trough, at approximately the same time, and recurved simultaneously along similarly shaped and spatially-proximate tracks.

II. TRACK AND INTENSITY

During early September, five TCs — Sally (23W), TS 24W, Tom (25W), Violet (26W), and Willie (27W) — formed in the monsoon trough. This very active monsoon trough moved northward, became reverse oriented, and by the final week of September had migrated to a relatively high latitude. As this monsoon trough exited the tropics, a new monsoon trough formed at low latitudes, and was the site of development for the next two TCs in the WNP: Yates and Zane (29W).

The tropical disturbance which became Yates was mentioned on the Significant Tropical Weather Advisory as early as 170600Z September, when a persistent area of deep convection was observed at low latitude just east of the international date line. At this time the WNP was still dominated by the reverse-oriented monsoon trough which contained Tom (25W), Violet (26W) and Willie (27W). The low latitudes of the WNP were dominated by high pressure and low-level easterly flow, and the pre-Yates tropical disturbance was the only significant area of deep convection which was deemed to have any chance of becoming a TC. During the next three days, this disturbance traveled westward into the Marshall Islands. Amounts of deep convection associated with this disturbance began to increase, along with a gradual increase in the amount and extent of deep convection throughout the rest of Micronesia. On 21 September, a small area of persistent deep convection consolidated northwest of Kwajalein. Visible and water-vapor satellite imagery indicated good upper-level anticyclonic outflow over this disturbance, prompting the JTWC to issue a TCFA at 210100Z. Over the next 24 hours, the small system showed no signs of development, but maintained its organization. Thus, a second TCFA was issued at 220100Z. During the night of 22 September, the pre-Yates tropical disturbance rapidly acquired well-organized cyclonically-curved convective cloud bands surrounding a small area of persistent deep convection over the LLCC. Based upon this improvement in convective organization, the first warning on Tropical Depression (TD) 28W was issued valid at 221800Z. Within three hours after its issuance, the first warning was amended to indicate that TD 28W was a tropical storm. The amended warning stated:

"Tropical Storm Yates (28W) is moving west-northwestward at 14 knots. Justification [for amendment]: this warning has been amended based on intensity. Satellite analysis indicates that this system is [of] tropical storm intensity. Due to its small size and diffluent [divergent] winds aloft, rapid intensification is expected...."

Yates did indeed intensify rapidly. During the period 221800Z to 231200Z it increased from a minimal tropical storm to a typhoon with an intensity of 115 kt (59 m/sec). The equivalent pressure fall of 57 mb during this 18-hour time period (or 3.2 mb/hr) met the criterion for explosive deepening (i.e., a decrease in the minimum sea-level pressure of a TC of 2.5 mb/hr for at least 12 hours) as defined by Dunnavan (1981). At 250000Z, Yates reached its peak intensity of 130 kt (67 m/sec) (Figure 3-28-1). Yates was a minimal super typhoon for only six hours, and then its intensity fell slightly to 125 kt (64 m/sec) as it passed between the islands of Saipan and Anatahan. During

the four-day period 250000Z to 290000Z, Yates remained a powerful typhoon as its intensity fluctuated slightly between 115 and 125 kt (59 to 64 m/sec) and maintained a very small eye which was, at times, cloud filled.

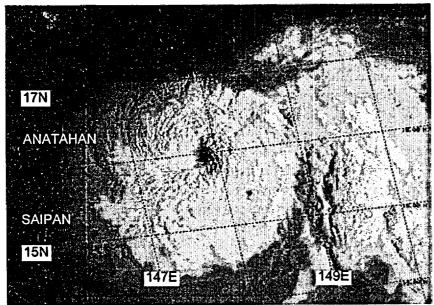


Figure 3-28-1 Yates at peak intensity of 130 kt (67 m/sec) (242319Z September visible DMSP imagery).

Late on 28 September, Yates began to recurve. It moved slowly toward the northnortheast on 29 September, and then on 30 September, it entered the deep-layer westerly air flow of the midlatitudes, turned more toward the east and accelerated. The final warning was issued valid at 011800Z October as the system neared the completion of its extratropical transition. Yates became a powerful extratropical low in the North Pacific after it crossed the international date line (Figure 3-28-2).

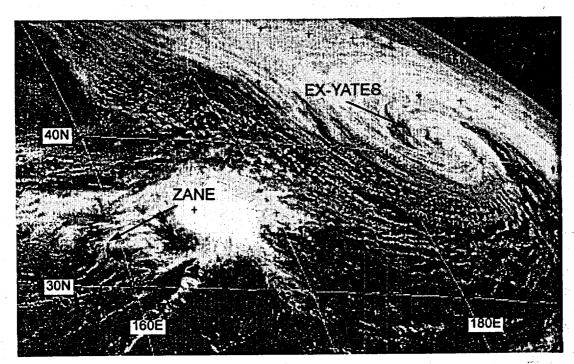


Figure 3-28-2 After recurvature, Yates became an intense extratropical low in the central North Pacific, while Zane (29W) slowed and dissipated (032331Z October visible GMS imagery).

III. DISCUSSION

a. Persistent pin-hole eye

Visible and infrared satellite imagery indicated that Yates possessed a very small, or "pinhole", eye (i.e., a diameter of 10 nm or less) throughout most of its life. Many typhoons which acquire a pin-hole eye usually evolve to possess a larger eye (see the summaries of Super Typhoon Dale (36W) and Super Typhoon Ward (1995)). The evolution from pin-hole eye to larger eye typically begins with the formation of concentric wall clouds. Having formed concentric wall clouds, the outer wall cloud contracts as the small eye and inner wall cloud collapse. Eye wall replacement processes are described more fully by Willoughby (1982, 1990). Yates was somewhat unusual in that it retained a pin-hole eye for four days.

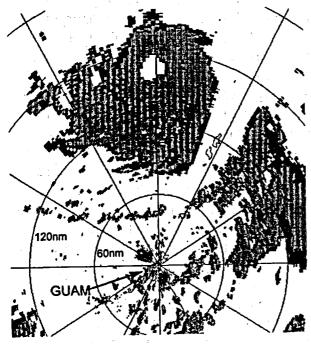


Figure 3-28-3 Yates maintained a well-defined 18 nm (33 km) diameter eye on NEXRAD as it passed to the north of Guam (251844Z September base reflectivity NEXRAD product).

b. Passage though Guam's NEXRAD coverage

On 25 September, Yates passed between the islands of Saipan and Anatahan. Its small eye passed approximately 50 nm (100 km) to the north of Saipan, 20 nm (40 km) to the south of Anatahan, and 155 nm (290 km) to the north of Guam. Yates was close enough to Guam to be scanned with Guam's NEXRAD (Figure 3-28-3). The following comments were received in an after-action report by the Andersen AFB NEXRAD operators:

"Yates' well-defined circular eye became visible on radar [at] 25/0131Z shortly after being upgraded to STY intensity and continued to track west at 14 kt average. [Its] symmetrical eye, with an average diameter of 18 nm [33 km], was well surrounded with up to ninety percent high reflectivity wall cloud. . . . [it] went out of range on 26/0834Z. . . Yates never came within [the] 124 nm (230 km) velocity range. . . Reflectivity products were sufficient to fix its eye and movement with a high degree of accuracy. . . ."

It is interesting to note that in Yates' case, the radar-observed eye was larger than the satellite-observed eye. On satellite, the eye diameter was approximately 10 nm (18 km) when not cloud filled. That the pin-hole eye of Figure 3-28-1 had a larger diameter on radar than that which was seen on the satellite imagery implies that cirrus of the wall cloud was obscuring the eye somewhat.

c. Segregation of TCs into families based upon monsoon trough evolution

The tendency of the monsoon trough of the WNP to form and then migrate northward lends itself to a natural segregation of TCs into "families" with the commonality among the TCs within each "family" being that they were associated with the same monsoon trough. The five-TC sequence of early September — Sally (23W), TS 24W, Tom (25W), Violet (26W), and Willie (27W) — all had in common an origin within the same monsoon trough. By late September, this monsoon trough moved northward, became reverse oriented, and migrated to higher latitude as TCs Tom (25W) and Violet (26W) carried it with them out of the tropics. As this trough exited the tropics, a new monsoon trough formed at low latitudes, and was the site of development for the next two

TCs in the WNP: Yates and Zane (29W). Yates and Zane therefore comprise another "family" by virtue of their development within the same monsoon trough.

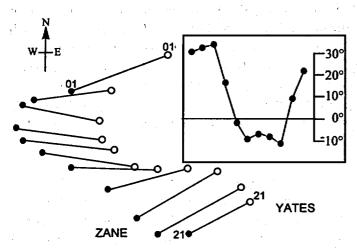


Figure 3-28-4 A schematic illustration of the similarly shaped and spatially proximate recurving tracks of both Yates and Zane (29W). Thin lines connect the TCs at 24 hour intervals beginning at 210000Z September and ending at 010000Z October. The inset shows the bearing of Yates from Zane at 24-hour intervals during the same time period. Positive values indicate Yates north of Zane.

d. Direct, semi-direct, and indirect TC interaction

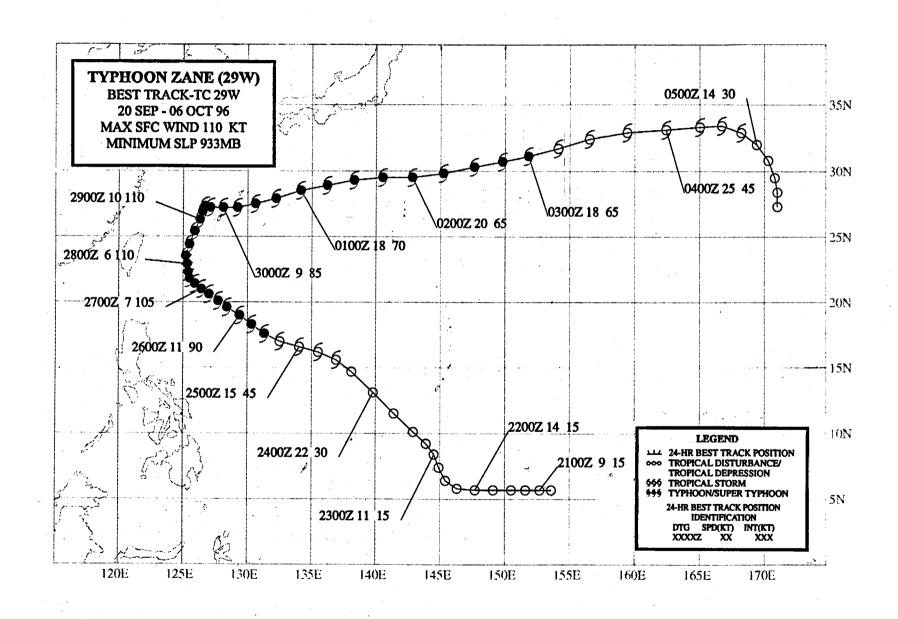
Like Tom (25W) and Violet (26W) before them, Yates and Zane moved on nearly identical spatially-proximate recurving tracks (Figure 3-28-4). The inset of Figure 3-28-4 shows the bearing of Yates from Zane. Note the initial cyclonic change of bearing, followed by a period of anticyclonic change of bearing, then as Yates recurved, the change of bearing was once again Although these two TCs cyclonic. approached to within 780 nm (1450 km), there is little evidence that the TCs were mutually advecting each other (i.e., the Fujiwhara effect) during any of the periods of relative cyclonic orbit. In the Systematic and Integrated Approach, there are three basic kinds of TC interactions: direct (a

mutual cyclonic orbit resulting from the TCs being advected by each other's outer winds), semi-direct (a mutual cyclonic orbit resulting from the alteration by one TC of the steering flow between the other TC and the subtropical ridge), and indirect (i.e., a mutual anticyclonic orbit resulting from the establishment of a ridge between the two TCs). Yates and Zane (29W) had motion characteristics suggestive of semi-direct and indirect TC interaction. The mutual anticyclonic orbit of Yates and Zane during the period 23 to 26 September (manifested in a south-of-west track for Yates) are typical of indirect TC interaction. The periods of mutual cyclonic orbit at the beginning and at the end of the tracks is consistent with semi-direct TC interaction. It is often difficult to differentiate between semi-direct and direct TC interaction, but one clue is often the separation distance. True direct interaction of two TCs usually occurs when the TCs are within 780 nm (1450 km) of each other. Yates and Zane were at this threshold, and it is possible that they may have interacted directly, especially at the end of their tracks when the cyclonic orbit increased rapidly.

TC interaction often results in complicated forecast scenarios. When Yates and Zane came abreast of one another at the same latitude, it was unclear which of the two would recurve first. Zane (29W) had been gaining latitude faster than Yates, and once south of Yates, it moved so as to be at a higher latitude. When Zane slowed near Okinawa, Yates turned to the north, accelerated, and moved to a higher latitude relative to Zane. Yates then recurved ahead of Zane.

IV. IMPACT

Because of Yates' small size, there was only minor damage on Saipan and Anatahan. On Saipan, Yates felled several trees and caused minor flooding. On Anatahan, where estimated winds of 80 kt (41 m/sec) were reported, tin roofs were blown off houses and the entire taro crop was destroyed. Only a handful of people live on the island and they were reported safe and in possession of plenty of food after the cyclone's passage.



TYPHOON ZANE (29W)

I. HIGHLIGHTS

Zane and Yates (28W) developed in the same monsoon trough, at approximately the same time, and recurved simultaneously along similarly-shaped and spatially-proximate tracks. The typhoon affected both Taiwan and Okinawa. Passing Okinawa, Zane came within range of Kadena's NEXRAD. After recurvature, Zane maintained its central deep convection despite being embedded in deep-layer westerly flow to the north of the subtropical ridge.

II. TRACK AND INTENSITY

During early September, five TCs — Sally (23W), TS 24W, Tom (25W), Violet (26W), and Willie (27W) — formed in the monsoon trough. This very active monsoon trough moved northward, and became reverse oriented. By the final week of September, it had migrated to a relatively high latitude as TCs Tom (25W) and Violet (26W) carried the trough with them out of the tropics. As this monsoon trough exited the tropics, a new monsoon trough formed at low latitudes, and was the site of development for the next two TCs in the WNP — Yates (28W) and Zane.

While the WNP was still dominated by the reverse-oriented monsoon trough which contained Tom (25W), Violet (26W) and Willie (27W), the low latitudes of the WNP were dominated by high pressure and low-level easterly flow. As Tom (25W) and Violet (26W) recurved, a new monsoon trough formed in Micronesia. Deep convection associated with this monsoon trough consolidated within two areas. The eastern area became Yates (28W) and the western area became Zane. The large area of deep convection which became Zane was larger than the one which became Yates (28W) and is a good example of a monsoon depression (Figure 3-29-1). It was first mentioned on the 201900Z Significant Tropical Weather Advisory. This monsoon depression moved westward and, typical of monsoon depressions, it was several days before deep convection persisted near the low-level circulation center. When the deep convection persisted near the LLCC, a TCFA was issued at 230600Z. A second TCFA was issued at 232030Z in order to reposition the alert box. Based on satellite intensity estimates of 25 kt (13 m/sec), the first warning on Tropical Depression (TD) 29W was issued, valid at 240000Z September. Remarks on this warning included:

"... Tropical Depression 29W is located in the monsoon trough equatorward of the subtropical ridge. TD 29W is located approximately 800 nm west of Typhoon Yates (28W). Satellite imagery indicates the presence of weak ridging to the southeast of 29W. The rapid north-northwest-ward movement of TD 29W is associated with the enhanced southerly steering component associated with the weak ridging between TD 29W and Typhoon Yates (28W)...."

The rationale for the motion of TD 29W in this remark is a good description of what is known as "indirect TC interaction" in the "Systematic and Integrated Approach". Yates' (28W) summary contains a more complete description of the interaction between Zane and Yates.

During the night of 24 September, deep convection rapidly consolidated over the LLCC of TD 29W and, on the warning valid at 241200Z, TD 29W was upgraded to Tropical Storm Zane. Soon after the formation of Zane's CDO, the peripheral cloudiness in the monsoon depression was suppressed and the areal extent and amount of deep convection became smaller. Moving northwestward, Zane intensified and became a typhoon at 251200Z. The peak intensity of 110 kt (57 m/sec) was reached at 280000Z, which was maintained until 291200Z. During this time, the typhoon moved on a slow northward track and passed approximately 90 nm (170 km) to the west of Okinawa. On 29 September, Zane slowed and made a sharp turn to the east, passing approximately

20 nm (40 km) to the north of the northern end of Okinawa (Figure 3-29-2) and, despite being embedded in westerly flow north of the subtropical ridge maintained typhoon intensity. On 02 October, Zane (still a typhoon) possessed a very unusual cirrus outflow pattern: cirrus debris streamed eastward on both the north and south sides of the system, evoking the analogy of debris being stripped from a comet by the solar wind (Figure 3-29-3a) (see the discussion). On 03 October, westerly shear finally began to have an effect, and the LLCC of Zane became partially exposed on the west side of the deep convection. At 031200Z, the final warning was issued, as Zane began its extratropical transition. After the final warning, the system moved east and then south as it encountered the vigorous outer circulation of the large intense extratropical low which was once Yates (28W) (see Figure 3-28-2 in Yates' (28W) summary).

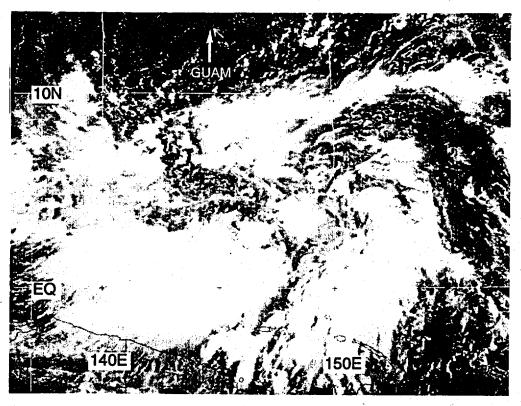


Figure 3-29-1 Zane originated from this monsoon depression located to the south of Guam (212224Z September visible GMS imagery).

III. DISCUSSION

a. Origin as a monsoon depression south of Guam

Zane began as a monsoon depression near Guam. Initially it was a large ensemble of mesoscale convective systems embedded within a region of lowered sea-level pressure. It lacked persistent central deep convection, and the maximum winds in the system were displaced outward from the low-level circulation center. Eventually as the system moved toward the northwest, the circulation intensified, and persistent central deep convection became established marking its transition to a conventional TC. Cam's (05W) summary contains a detailed discussion of the structure and evolution of monsoon depressions in the WNP.

b. Passage within range of Guam's and Kadena's NEXRADs

When forming near Guam, some of the rainbands (that were part of the monsoon depression which became Zane) came within the range of Guam's NEXRAD. One of the most interesting features of these rainbands was the presence of mesoscale vortices associated with convective cells in these rainbands. These mesovortices were detected by the meso-alert algorithm of the NEXRAD. Mesoscale vortices are often associated with tornadic activity over land, however, tornadic activity (e.g., tornadic waterspouts) have yet to be associated with NEXRAD-observed mesoscale vortices near Guam. They frequently are seen when tornadic activity is occurring in TC rainbands over land in the US mainland.

When Zane passed close to Okinawa, it came within range of the NEXRAD's velocity detection capability. Nothing unusual was noted as the well-defined radar eye of Zane passed. The base velocity product showed maximum inbound and outbound velocities on the order of 115 kt (59 m/sec) at altitudes of approximately 5,000 ft.

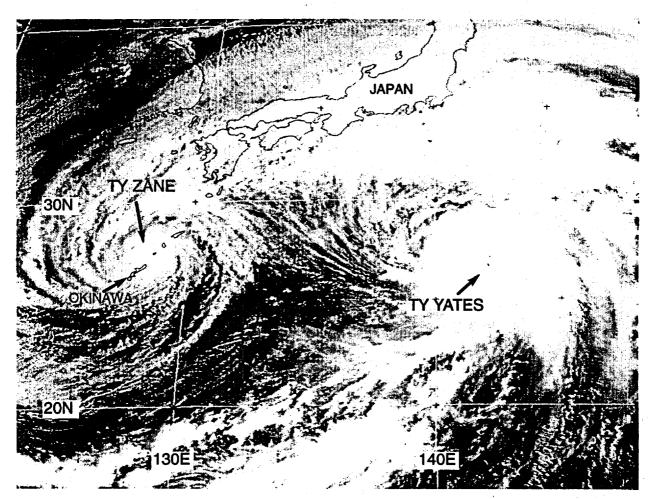


Figure 3-29-2 The rainbands of Zane sweep across Okinawa while at its closest point of approach to that island. Typhoon Yates (28W) is seen approximately 900 nm (1700 km) to the east of Zane (292224Z September visible GMS imagery).

c. Unusual persistence as a tropical cyclone while embedded in midlatitude westerlies

On 02 October, Zane (still a typhoon) possessed a very unusual cirrus outflow pattern: cirrus debris streamed eastward on both the north and south sides of the system, evoking the analogy of debris being stripped from a comet by the solar wind (Figure 3-29-3a). Water-vapor derived winds clearly show the upper-level winds to the north and south of Zane were from the west (Figure 3-29-3b). Zane was moving approximately 20 kt (37 km/hr) to the east-northeast at this time, while the azimuthally averaged 200-mb wind (at a radius of 300 nm) around the TC was from the west at approximately 50 kt. One might expect that a TC in such an environment would shear apart. This did not happen to Zane. The maintenance of Zane's CDO under apparent shearing conditions, and the near symmetry of the cirrus outflow within strong westerly winds aloft are unusual phenomena that raise questions about the relationship between the structure of a TC and the vertical shear of the horizontal wind.

IV. IMPACT

No reports of serious damage or injuries in Okinawa were received at the JTWC. About US \$50 thousand in damage was reported by US military installations on Okinawa —mostly downed trees and power lines. Another US \$118 thousand in damage was reported on the island, mostly to crops. Highest wind gusts reported on Okinawa were 79 kt (41 m/sec) at Kadena AB and 64 kt (33 m/sec) at Naha. Up to 12 inches (307 mm) of rain soaked the island. In Taiwan, heavy rains from Zane triggered mudslides that killed two people.

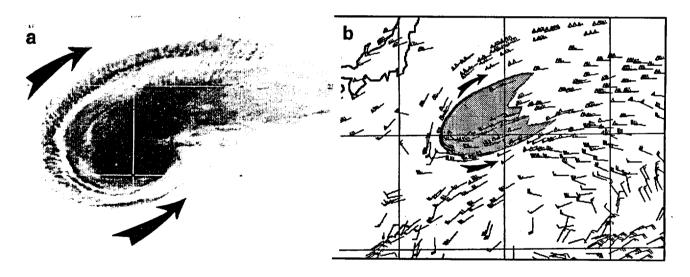
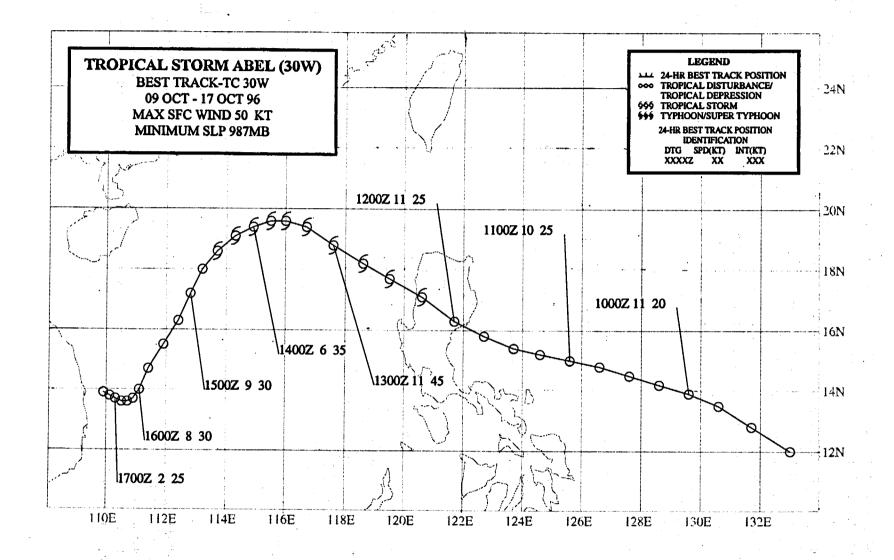


Figure 3-29-3 (a) Cirrus outflow is carried off to the east by strong upper-level westerly winds on both the north and south sides of Zane (021624Z October infrared GMS imagery, inverted-IR enhancement). (b) Water-vapor derived upper-tropospheric winds show Zane (the shaded region) was completely embedded in a westerly airstream. The divergence from the typhoon's convection caused the winds to split and go around the TC (021200Z October water-vapor derived upper-tropospheric winds).



TROPICAL STORM ABEL (30W)

I. HIGHLIGHTS

Abel originated from a monsoon depression in the Philippine Sea, crossed Luzon, and became a tropical storm in the South China Sea. Forced to move southwestward by the northeast monsoon, it dissipated over water while approaching the coast of southern Vietnam.

II. TRACK AND INTENSITY

At the beginning of October, Yates (28W) and Zane (29W) recurved and moved into the midlatitudes. After this, for about one week, the low latitudes of the WNP became relatively free of deep convection, and there was a break in TC activity. By the end of the first week of October, amounts of deep convection began to increase in the low latitudes of the WNP, and became concentrated within two large areas: one near Guam and the other north of the Marshall Islands. The area of deep convection located near Guam moved westward and became a monsoon depression in the Philippine Sea. With the help of animated high-resolution visible satellite imagery, a LLCC was detected south of a band of persistent deep convection, embedded in the large cyclonic circulation of the monsoon depression. This LLCC was mentioned on the 100600Z October Significant Tropical Weather Advisory. Shortly thereafter, at 100730Z, the JTWC issued a TCFA when conditions appeared to favor the formation of a TC. Remarks on the TCFA included:

"... Latest animated visual satellite imagery indicates a well defined low-level circulation has developed [east of the Philippines]. Newly developed convection is primarily to the north of the circulation center but is showing signs of improved organization..."

The first warning on Tropical Depression (TD) 30W was issued valid at 110000Z. Remarks on the first warning included:

"A tropical depression has formed in the Philippine Sea approximately 80 nm east-northeast of Catanduenas Island in the Philippines. Animated visual satellite imagery . . . and data from several ships . . . indicates that a partially exposed 1003 mb low-level circulation exists within a larger monsoonal circulation that stretches almost 400 nm to the northeast of the [LLCC]. . . ."

On 12 October, the system crossed the island of Luzon and entered the South China Sea. Perhaps as a result of lee-side effects, northerly gale-force winds were reported over water as soon as the low-pressure center reached the northwestern tip of Luzon. In real time, satellite intensity estimates below 35 kt (18 m/sec) were favored over the gale-force ship reports, and TD 30W was upgraded to Tropical Storm Abel on the warning valid at 131200Z. In post analysis, however, the satellite imagery was reevaluated, the ship reports of gale force winds were given a higher weight, and TD 30W became a tropical storm at 120600Z. Abel reached its peak intensity of 50 kt (26 m/sec) at 121200Z.

On 14 October, Abel began to move toward the southwest under the influence of high pressure over southern China, which contributed to strong low-level northeasterly flow to Abel's west and north. While moving toward the southwest, Abel began to weaken. The deep convection accompanying the well defined LLCC on 16 October (Figure 3-30-1) decayed, and the final warning was issued, valid at 170600Z, as the system dissipated over water while approaching the coast of southern Vietnam.

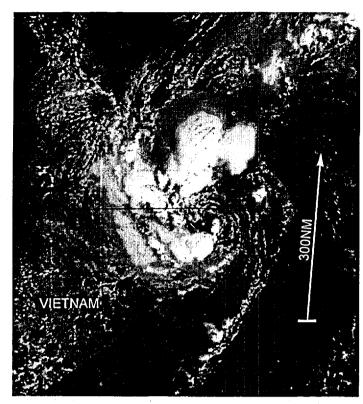


Figure 3-30-1 Abel moves slowly toward the coast of southern Vietnam, its well-defined LLCC is surrounded by cells of deep convection (160331Z October visible GMS

III. DISCUSSION

Unusual structure revealed by animated visible satellite imagery

When Abel was forming east of the Philippines, animation of visible satellite imagery indicated that the LLCC was displaced well to the south of the deep convection and also well to the south of the center of symmetry of the cirrus outflow (Figure 3-30-2). It is common for satellite fixes to be too far north in the monsoon depression stage of TC development, but in the case of Abel, the LLCC was unusually distant from the deep convection and the center of symmetry of the upper-level anticyclonic pattern of the cirrus. Synoptic data, and scatterometer data also supported this large displacement.

IV. IMPACT

As the weakening Abel approached Vietnam, rough seas overturned 146 boats and two fishermen were lost. At least 11 other people were reported missing.

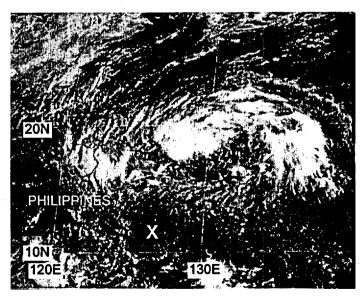
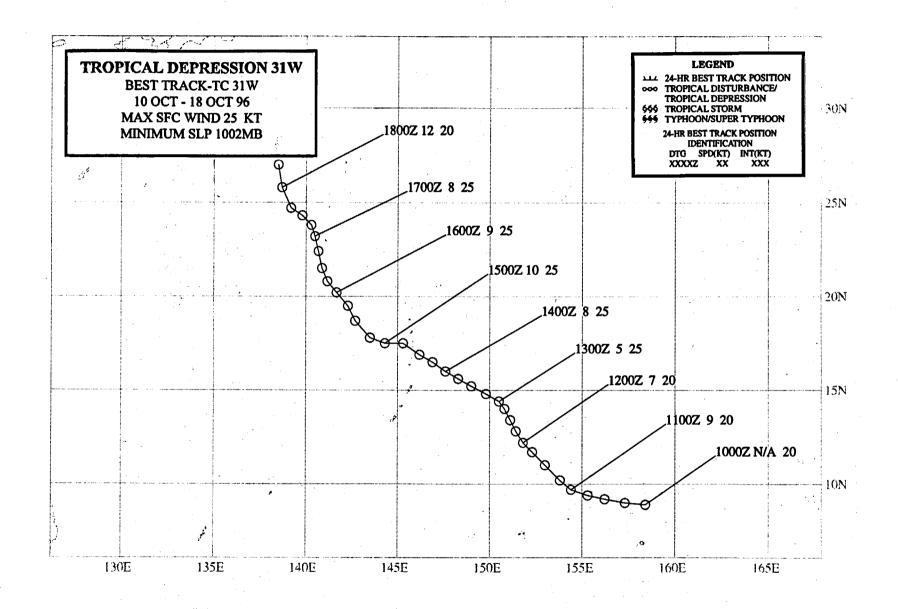


Figure 3-30-2 Animation showed that the LLCC (labeled, X) of the pre-Abel monsoon depression was displaced unusually far from its deep convection and from the center of symmetry of its upper-level cirrus outflow (102331Z October visible GMS imagery).



TROPICAL DEPRESSION 31W

For much of October, winds throughout most of Micronesia were light and variable in association with a weak monsoon trough. Deep convection (loosely organized into discrete ensembles of MCSs) was located in an east-west zone across the low latitudes of the WNP. Several of the tropical disturbances in this maximum cloud zone became significant TCs. The first TC of October, Abel (30W), originated from a monsoon depression in this cloud band. The next two TCs following Abel — Tropical Depression (TD) 31W and Typhoon Beth (32W) — developed simultaneously during the middle of the month (Figure 3-31-1). The tropical disturbance which became TD 31W originated southeast of Guam, and was located approximately 600 nm (1100 km) southeast of the tropical disturbance which became Beth (32W). This tropical disturbance was first mentioned on the 100600Z October Significant Tropical Weather Advisory. On 13 October, the pre-TD 31W disturbance acquired a clearly defined LLCC on satellite imagery, prompting the JTWC to issue a Tropical Cyclone Formation Alert at 130330Z October. The first warning on TD 31W, valid at 130600Z, soon followed when satellite intensity estimates indicated 25 kt (13 m/sec).

Moving toward the northwest, TD 31W exhibited a shear-type cloud pattern (Figure 3-31-2) for all of its life. Satellite intensity estimates and the best-track intensities remained at 25 kt (13 m/sec) for several days. During the night of 17 October, the deep convection associated with TD 31W decreased in amount and became sheared well to the east of the LLCC. The final warning on TD 31W was issued, valid at 171200Z, as the system dissipated over water.

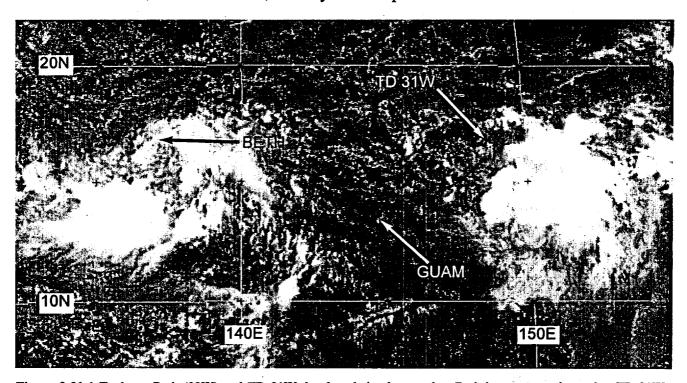


Figure 3-31-1 Typhoon Beth (32W) and TD 31W developed simultaneously. Beth became a typhoon, but TD 31W failed to become a mature TC (122331Z October visible GMS imagery).

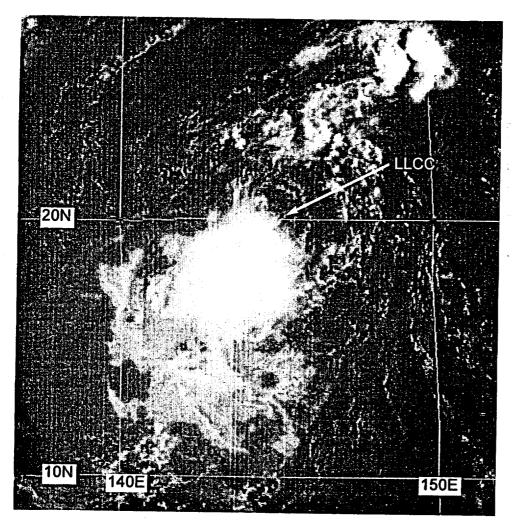
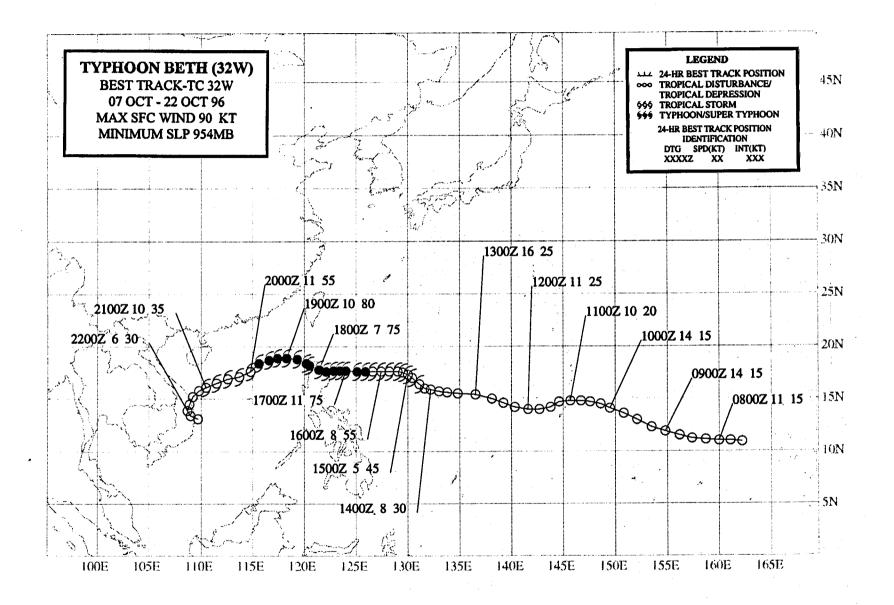


Figure 3-31-2 For all its life, TD 31W exhibited a shear-type cloud pattern. The LLCC is located to the north of the deep convection in this image (152224Z October visible GMS imagery).



TYPHOON BETH (32W)

I. HIGHLIGHTS

The tropical disturbance which became Beth was first detected in the eastern Caroline Islands. It developed very slowly, and four Tropical Cyclone Formation Alerts were issued on the system prior to the first warning. Passing over Guam, it produced a thunderstorm with a spectacular display of cloud-to-ground lightning (unusual in the maritime tropics). Beth became a typhoon in the Philippine Sea and passed over Luzon where loss of life was reported. Encountering the north-east monsoon in the South China Sea, it turned to the southwest, weakened, and made landfall in central Vietnam.

II. TRACK AND INTENSITY

For much of October, winds throughout most of Micronesia were light and variable in association with a weak monsoon trough. Deep convection (loosely organized into discrete ensembles of MCSs) was located in an east-west zone across the low latitudes of the WNP. Several of the tropical disturbances in this maximum cloud zone became significant TCs. The first TC of October, Abel (30W), originated from a monsoon depression in this cloud band. The next two TCs—Tropical Depression (TD) 31W and Beth (32W)—developed simultaneously during the middle of

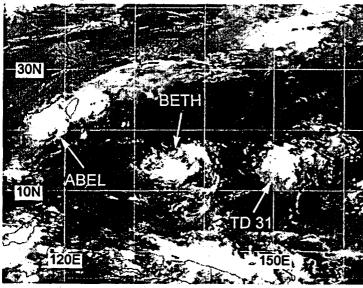


Figure 3-32-1 The tropical disturbances which became Beth and TD 31W developed simultaneously while Abel (30W) moved across the South China Sea (122331Z October infrared GMS imagery).

the month (Figure 3-32-1). The tropical disturbance which became Beth originated in the eastern Caroline Islands. It was first mentioned on the 071800Z Significant Tropical Weather Advisory. The system moved westward, and in the late afternoon of 11 October, synoptic data from Guam and Saipan, visible satellite imagery, and NEXRAD products indicated that a weak LLCC was associated with an area of increasing deep convection near Guam and Saipan. This prompted the JTWC to issue the first TCFA at 110730Z. At 111200Z, a second TCFA was issued in order to reposition the alert box to account for indications on NEXRAD data that a second LLCC had formed to the east of Guam. At 120130Z October, a third TCFA was issued to move the alert box further to the

west to incorporate indications on visible satellite imagery that the primary LLCC had moved to a position 260 nm (480 km) west of Guam. The pre-Beth tropical disturbance moved west and did not intensify, although conditions still appeared favorable for further development, and a fourth TCFA was issued at 130000Z. During the night of 13 October, the deep convection in the pre-Beth tropical disturbance consolidated near the LLCC and became organized into a well-defined curved band. The first warning, valid at 131200Z, was issued on Tropical Depression (TD) 32W. The cloud pattern of TD 32W evolved into a sheared pattern type with the LLCC exposed on the eastern side (Figure 3-32-2). When satellite imagery indicated an intensity of 35 kt (18 m/sec), TD 32W was

upgraded to Tropical Storm Beth on the warning valid at 150000Z. Beth became a typhoon at 161200Z and reached its peak intensity of 90 kt (46 m/sec) at 171200Z just prior to landfall on the

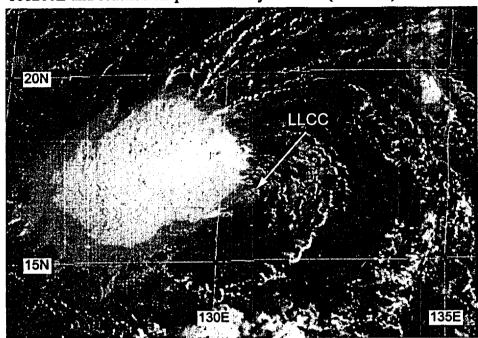


Figure 3-32-2 Beth's LLCC is partially exposed to the east of the deep convection, indicating the presence of easterly vertical wind shear (142224Z October visible GMS imagery).



Figure 3-32-3 Beth acquires a small visible eye shortly before reaching peak intensity (170424Z October visible GMS imagery).

east coast of northern Luzon (Figure 3-32-3). While crossing northern Luzon, Beth weakened only slightly to 75 kt (39 m/sec), and then reintensified to 80 kt (41 m/sec) at 181200Z when it entered the South China Sea. The period of reintensification was short-lived and by the morning of 20 October, the deep convection became sheared to the east of Beth's LLCC as the system weakened steadily over water. As Beth began to weaken, it began to move toward the westsouthwest in response to high pressure over south-

ern China and a strengthening of low-level northeasterly flow to its west and north. The final warning was issued, valid at 211800Z, as the poorly defined LLCC reached the coast of central Vietnam and dissipated.

III. DISCUSSION

a. Lightning in the maritime tropics

On the night of 11 October, a thunderstorm associated with the pre-Beth tropical disturbance produced a spectacular display of cloud-to-ground (CG) lightning on Guam. Frequent CG lightning is rare on Guam, even in large cumulonimbus clouds with tops exceeding 50,000 ft. Indeed, lightning frequencies are low in general over the maritime regions when compared with lightning frequencies within thunderstorms over large land areas (Orville and Henderson 1986). The cause of reduced lightning frequencies in maritime cumulonimbus clouds has been narrowed to two primary mechanisms:

- 1) reduced vertical velocities in maritime thunderstorms; and,
- 2) differences between the continental versus maritime aerosols which comprise the cloud condensation nuclei.

A more detailed discussion of the mechanisms of cloud electrification are beyond the scope of this summary.

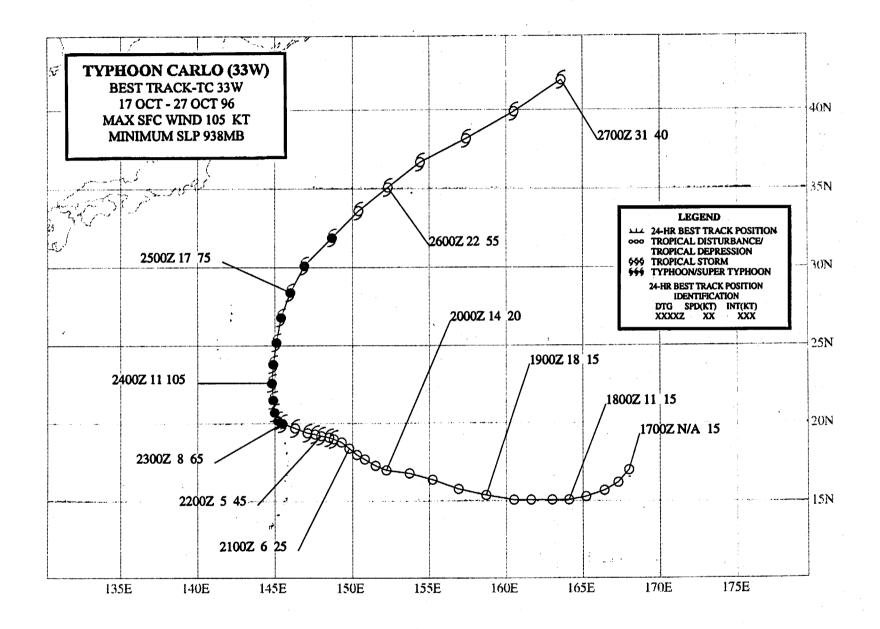
In the case of the relatively frequent CG lightning discharges in the 11 October Guam thunderstorm, only one other unusual factor was noted: reflectivity values as high as 60 dBZ on the NEXRAD composite reflectivity product persisted in the core of the thunderstorm as it moved southwestward across Guam.

b. Intensification of a sheared TC

One of the factors known to influence genesis and development of a TC is vertical shear of the horizontal wind: too much shear, and the TC is torn apart. Zehr (1992) found that an 850-200 mb wind shear of 15 kt (8 m/sec) or greater was unfavorable for TC genesis and development. On the morning of 15 October, Beth possessed a shear-type cloud pattern (Figure 3-32-2), and the LLCC was partially exposed on the east side of the deep convection. Shear is often detrimental to the further development of a TC. In Beth's case, however, the system intensified despite the shear and by 17 October, Beth was a typhoon with a visible eye and a symmetrical pattern of cirrus outflow (Figure 3-32-3). It is a difficult forecast problem to determine whether vertical shear is going to inhibit development, or whether the TC will continue to develop despite a shearing environment. Fundamental questions remain in the case of intensification in a sheared environment: does the TC outflow manage to overcome the shear? Does the shear decrease? Do changes occur in its vertical profile?

IV. IMPACT

At least three people were reported dead after Beth moved across the northern Philippines. The TC tore away roofs, smashed windows, and triggered floods. In the hardest-hit province of Cagayan, Beth damaged municipal buildings and crops, and eroded roads.



TYPHOON CARLO (33W)

I. HIGHLIGHTS

Carlo's TUTT-cell-induced formation is one of the best examples of this process witnessed during 1996. Water-vapor imagery provided detailed information on the evolution of upper-level winds, clouds, and moisture for this event. Carlo reached its peak intensity after its apparent "point of recurvature" — unusual behavior of TCs which recurve. Accelerating to a speed of 30 kt (55 km/hr), Carlo was absorbed into the frontal cloud band of an intense extratropical low.

II. TRACK AND INTENSITY

On 17 October, three TCs were active in the western part of the WNP: Abel (30W) (in the South China Sea), TD 31W (halfway between Guam and Japan), and Beth (32W) (near the coast of Luzon). Elsewhere in the tropics of the WNP, amounts of deep convection were below normal and the low-level winds were predominantly from the east. The only area of deep convection considered to have potential for TC formation was associated with a TUTT cell, and was centered near 17°N 168°E. It was first mentioned on the 170600Z October Significant Tropical Weather Advisory. Moving westward on the northern side of the TUTT cell (Figure 3-33-1), this tropical disturbance (which became Carlo) gradually became more organized. At 200230Z October, the JTWC issued a TCFA when persistent deep convection (located in a region of divergent upper-level flow) consolidated near the LLCC. Based on satellite intensity estimates of 25 kt (13 m/sec), the first warning on Tropical Depression (TD) 33W was issued valid at 210000Z.

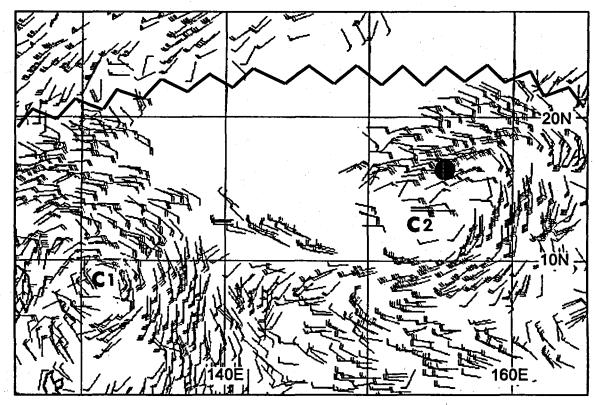


Figure 3-33-1 The location of the LLCC of the pre-Carlo tropical disturbance (shown by the black dot) is under the easterly upper-level flow to the north of a TUTT cell (labeled, C2). Another TUTT cell (labeled, C1) is located further to the west. The zig-zag line indicates the upper-level subtropical ridge axis (191025Z October GMS water-vapor winds).

Developing a CDO, TD 33W was upgraded to Tropical Storm Carlo on the warning valid at 211200Z. Carlo became a typhoon at 230000Z as a small ragged eye formed within its CDO (Figure 3-33-2). After becoming a typhoon, Carlo turned northward and further intensified, reaching a peak intensity of 105 kt (54 m/sec) at 240000Z. Late on 24 October, Carlo began a gradual turn toward the northeast accompanied by an increase in it speed of translation. Westerly shear began to affect Carlo and by 250000Z the typhoon weakened to 80 kt (41 m/sec); at 251800Z the intensity dropped to 60 kt (31 m/sec). The system continued to weaken as it accelerated to the northeast. The final warning was issued, valid at 261800Z, as the system moved northeastward at

22N 18N 142E

Figure 3-33-2 An overshooting cloud top casts a shadow over Carlo's incipient eye (222101Z October visible DMSP imagery).

29 kt (54 km/hr), lost its deep convection, and began to merge with a frontal cloud band.

III. DISCUSSION

a. Tropical cyclogenesis induced by a TUTT cell

Water vapor imagery (Figure 3-33-3) showed that Carlo formed in an area of upper-level moisture (with embedded deep convection) on the north side of a TUTT cell. Typical of TCs which form in association with TUTT cells. Carlo formed north of 15°N latitude, was embedded in low-level easterly flow, and was isolated in a cloud-minimum region south of the subtropical ridge. See Joy (12W) for a more detailed discussion of TUTT-related TC genesis.

b. Peak intensity after making a sharp turn toward the north

Most typhoons that undergo classic recurvature (i.e., a roughly "<"-shaped track which features initial steady west-northwestward motion, then a northward turn while slowing, followed by an acceleration toward the northeast) reach peak intensity at, or before, the point of recurvature; where the point of recurvature is identified as that point where the typhoon reaches its westernmost longitude (JTWC, 1994). Many TCs do not undergo classic recurvature. Some never recurve, while others move on a track type designated by the Japan Meteorological Agency (JMA) (1976) as north-

oriented. North-oriented TC tracks have been renamed poleward-oriented tracks in Carr and Elsberry (1996) to make the concept applicable to both the Northern and Southern Hemispheres. TCs that move on north-oriented tracks move generally on long, northward paths from their genesis location and may feature large meanders and abrupt turns to the left or right (Lander 1996). North-oriented tracks occur predominantly during July through October. Carr and Elsberry found that a TC may undergo north-oriented motion for only a portion of its track — even if some, or most, of the track was of some other type (e.g., straight moving). A characteristic behavior of some TCs undergoing north-oriented motion is reaching peak intensity after acquiring a persistent eastward component of motion, but before the TC begins to significantly increase its speed of translation within the "accelerating westerlies" regime north of the subtropical ridge. Synoptic regimes associated with specific TC behavior, such as "poleward oriented" and "accelerating westerlies", are described in Carr and Elsberry (1996), and briefly at the beginning of this chapter.

Carlo reached peak intensity while moving north-northeastward on the north-oriented leg of its track. It weakened as it entered the "accelerating-westerly" regime north of the subtropical ridge.

IV. IMPACT

No reports of damage or injuries were received at JTWC.

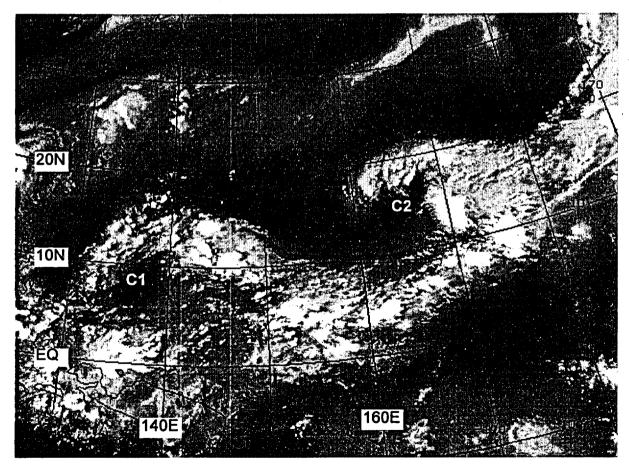
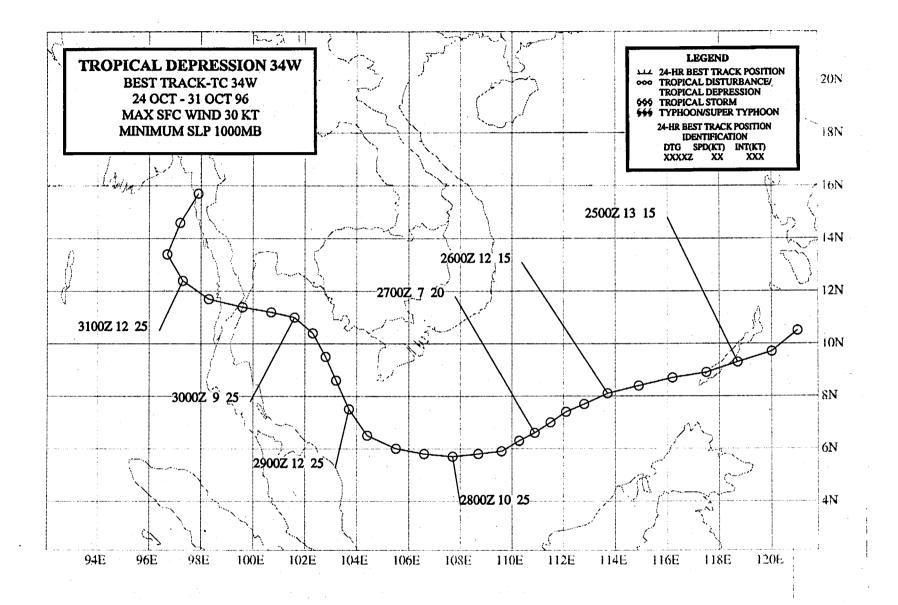


Figure 3-33-3 Two TUTT cells (C1 and C2) show prominently in water vapor imagery. Carlo formed under the moist tongue on the north side of TUTT cell C2 (180033Z October water vapor GMS imagery).



TROPICAL DEPRESSION 34W

The tropical disturbance which became Tropical Depression (TD) 34W originated from an area of persistent deep convection over the central Philippines. As the deep convection drifted westsouthwestward across the South China Sea, a weak LLCC persisted to the eastern edge of the convection. The tropical disturbance was first mentioned on the 270600Z October Significant Tropical Weather Advisory when water vapor satellite imagery indicated that an upper-level anticyclone was forming over the deep convection. Although the cloud system remained poorly organized (Figure 3-34-1), JTWC anticipated further development and issued the first TCFA at 272030Z. A scatterometer pass over the system at 280251Z indicated a well-defined LLCC with wind speeds of 15 to 25 kt (8 to 13 m/sec) on its north side and equatorial westerlies to the south. A second TCFA followed at 282030Z. Based upon ship reports and satellite intensity estimates of 25 kt (13 m/sec), JTWC issued the first warning on TD 34W valid at 290600Z. TD 34W tracked northwestward across the Gulf of Thailand, crossed the Isthmus of Kra and became completely disorganized after moving into the Bay of Bengal. The final warning was issued valid at 301800Z. On 31 October, the remnants of TD 34W turned northward and dissipated over southern Myanmar. In postanalysis, a ship report near the LLCC of 30-kt winds and 1004 mb pressure at 271200Z was used to upgrade the maximum intensity of the best track to 30 kt.

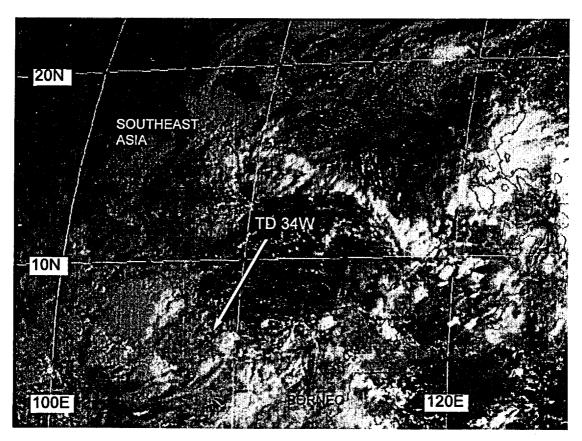
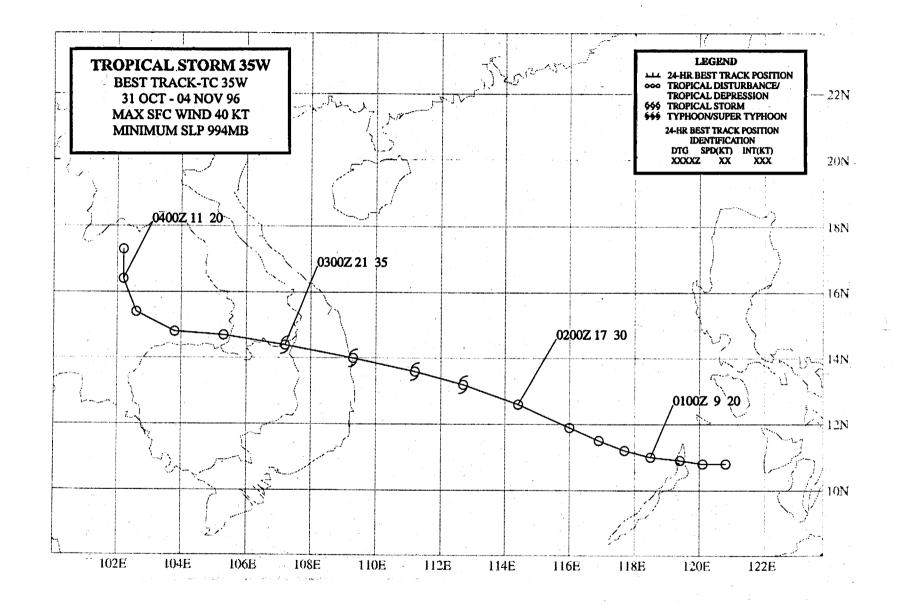


Figure 3-34-1 TD 34W moves west-southwestward in the South China Sea. Most of the deep convection lies to the west of the LLCC (272331Z October visible GMS imagery).



TROPICAL STORM 35W

On the last day of October, the tropical disturbance that became Tropical Storm (TS) 35W formed over the Philippines at nearly the same location as Tropical Depression (TD) 34W had formed a week earlier. The tropical disturbance was first mentioned on the 010600Z November Significant Tropical Weather Advisory when a persistent area of deep convection was observed over the South China Sea to the west of a weak LLCC in the Sulu Sea. The convection persisted and JTWC issued a TCFA at 011430Z. Falling pressures (3 mb in 24 hours), 25-kt synoptic reports and satellite intensity estimates led to the issuance of the first warning valid at 020000Z. The TC moved westward and acquired the structure of a monsoon depression (Figure 3-35-1) as it approached Vietnam. A final warning was issued, valid at 030600Z, as the remnants of the cyclone dissipated over Southeast Asia.

In postanalysis, synoptic reports and satellite imagery indicate that this TC most probably reached tropical storm intensity at 020600Z, and peaked at 40 kt six hours later. Thus, TD 35W was redesignated as TS 35W.

It is interesting to note that TS 35W was accompanied in the Southern Hemisphere by TC Melanie/Bellamine (05S)(Figure 3-35-2), as the TC activity in the Southern Hemisphere got off to a prolific start during the latter half of 1996.

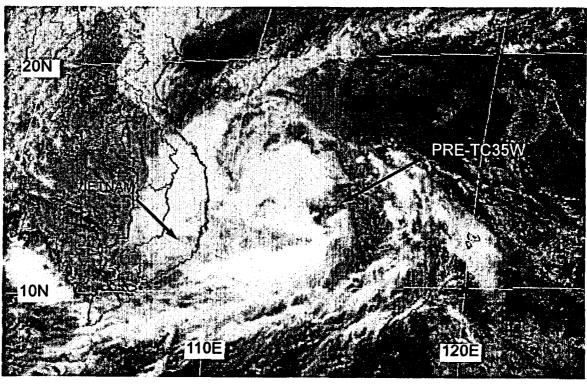


Figure 3-35-1 The monsoon depression just to the east of central Vietnam is approaching tropical storm intensity (020424Z November visible GMS imagery).

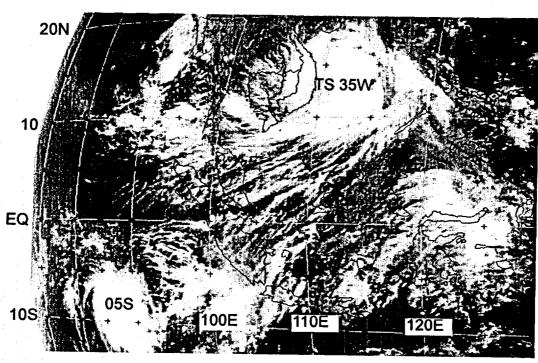
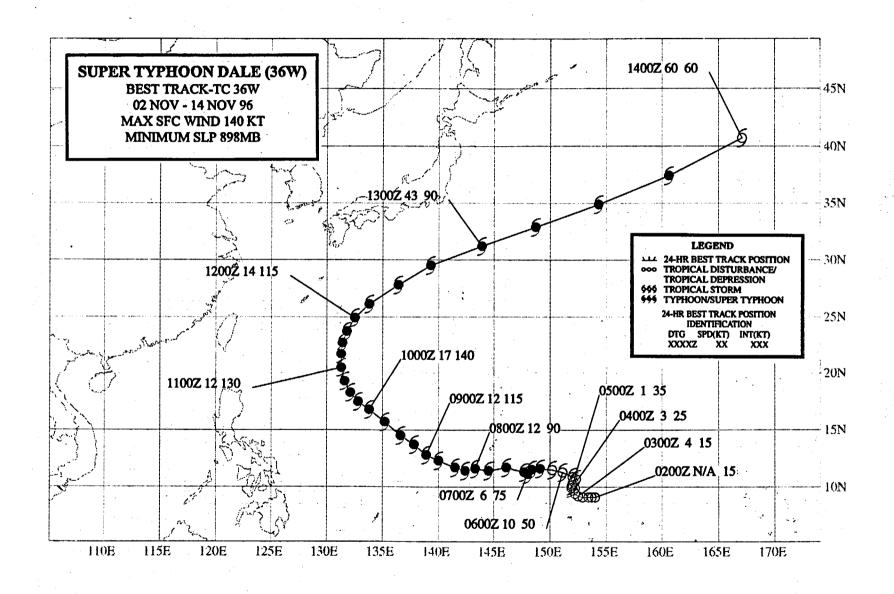


Figure 3-35-2 TS 35W is accompanied by TC Melanie/Bellamine (05S) in the Southern Hemisphere (020424Z November infrared GMS imagery).



SUPER TYPHOON DALE (36W)

I. HIGHLIGHTS

Dale was a large and very intense typhoon that formed at the eastern end of the near-equatorial trough. Its passage resulted in phenomenal seas and surf on Guam's western shore. The equatorial westerly wind burst that preceded Dale's formation was accompanied by very low sea-level pressure reports along the equator. Passing 110 nm to the south of Guam, Dale was observed by Guam's NEXRAD. Dale caused an estimated \$3.5 million worth of damage on Guam.

II. TRACK AND INTENSITY

From late October through the first day of November, the tropics of the WNP were dominated by easterly low-level wind and upper-level westerly wind; and, with the exception of the South China Sea, deep convection was disorganized and widely scattered. Beginning on 02 November, the amount of deep convection in the low latitudes of the WNP began to increase in association with lowering pressure throughout Micronesia accompanied by the onset of a near-equatorial trough along 5°N. On 03 November, the deep convection consolidated into two distinct clusters: one centered near 7°N 138°E (which became Ernie (37W)), and the other centered near 8°N 150°E (which became Dale). The pre-Dale cluster of deep convection was first mentioned on the 030600Z November Significant Tropical Weather Advisory when satellite imagery and synoptic data indicated the presence of a cyclonic circulation accompanied by a relatively low central pressure (1002 mb) and extensive divergence aloft (as indicated by animated water-vapor GMS imagery). With a continued fall of the central pressure, and improvements to the satellite cloud signature, a Tropical Cyclone Formation Alert was issued at 031800Z, followed by the first warning on Tropical Depression (TD) 36W, valid at 040600Z.

With an extensive surge in the southwesterly flow to its south and equally strong easterly winds to its north, TD 36W remained nearly stationary for approximately 24 hours while it slowly gained intensity. On the warning valid at 151200Z, TD 36W was upgraded to Tropical Storm Dale based upon satellite intensity estimates of 35 kt (18 m/sec) and a buoy report indicating that the central pressure had fallen below 996 mb (indicative of winds of at least 37 kt on the Atkinson and Holliday (1977) wind-pressure relationship). After becoming a tropical storm, Dale began to move westward, intensified, and became a typhoon at 061800Z. At approximately 071400Z Dale (moving west along 11.5°N) passed 110 nm (205 km) to the south of Guam where peak gusts reached 74 kt (38 m/sec) and high waves inundated some coastal roads and overtopped 100-ft (30-m) sea cliffs (see the Discussion and the Impact sections). Dale came within range of Guam's NEXRAD, which detected winds in excess of 100 kt (51 m/sec) in the lower troposphere (see the Discussion section).

On 09 November, while to the west of Guam in the Philippine Sea, Dale became a super typhoon with a peak intensity of 140 kt (72 m/sec) (Figure 3-36-1). On 10 November, Dale slowed and began a turn toward the north, and on 11 November reached its point of recurvature (i.e., the westernmost longitude). After recurvature, Dale accelerated rapidly to the east-northeast reaching translation speeds in excess of 60 kt (110 km/hr) after 140000Z. The final warning was issued, valid at 131800Z, when completion of extratropical transition was expected within six hours.

III. DISCUSSION

a. Extremely low equatorial sea-level pressure associated with Dale's formation

The sea-level pressure (SLP) along the equator has spatial and temporal variations of small

magnitude when compared with the magnitude of the SLP variations at higher latitudes. In the mean, the global equatorial SLP ranges from a maximum of approximately 1015.5 mb in the eastern Atlantic to a minimum of approximately 1008.5 mb in the WNP (Sadler et al. 1987). Lacking the Coriolis effect, and large inertial forces (e.g., centrifugal forces in atmospheric vortices such as typhoons), the pressure gradients on the equator must only be sufficient to drive the wind against friction. As such, a pressure gradient of 1 mb per 1000 km can support a sustained 10-m marine surface wind of 20 kt (10 m/sec). Even the vast easterly wind flow across the tropical Pacific is accompanied by an east-west pressure drop (along the equator) of only 4 mb from the eastern equatorial Pacific to the WNP. Given this background, it is now clear that the very low SLP readings of 1002 mb, and SLP changes of 10 mb along the equator in the WNP during the life of Dale are extraordinary.

While Dale and Ernie (37W) were forming at low-latitude in the WNP, the SLP throughout Micronesia was steadily falling. Even along the equator, to the south of the developing Dale, the SLP steadily fell to extraordinarily low values (Figures 3-36-2 and 3-36-3). On 04 November, several ships near the equator reported a SLP of 1002 mb or less. Values of SLP this low are rarely

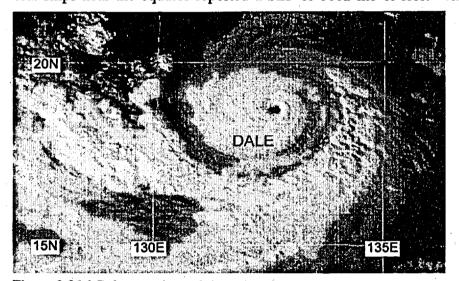


Figure 3-36-1 Dale nears its peak intensity of 140 kt (72 m/sec) (090530Z November visible GMS imagery).

seen along the equator. Morrissey (1988) examined the SLP reports of ships within two degrees of the equator along a principal north-south shipping lane between 148°E to 152°E. The ship reports used by Morrissey were extracted from the Comprehensive Ocean-Atmopshere Data Set (COADS) for an 80-year (1900-1979) period. From his analysis (Figure 3-36-4), few, if any, SLP reports below 1004 mb are found along the equator in this region. Ironically,

approximately 10 days after the very low SLP readings (and after Dale had exited the tropics), the equatorial SLP and the SLP throughout Micronesia rose to exceedingly high values. The SLP of 1013.5 mb on the equator on 14 November was, according to Figure 3-36-4, about as high as the SLP ever gets there.

b. Dale as seen by Guam's NEXRAD

On the night of 07 November, Dale passed 110 nm (205 km) to the south of Guam. Guam experienced the peripheral rain bands of Dale, but never entered the eye wall cloud (Figure 3-36-5). For much of the time during Dale's closest point of approach (CPA), Guam remained within a dry wedge between the outer rain bands and the eye wall cloud. The air was laden with salt spray, and some light rain which allowed the NEXRAD to obtain a deep vertical profile of the wind velocity (Figure 3-36-6). The highest winds of approximately 100 kt (51 m/sec), persisted in a layer between about 6,000 and 13,000 ft. At the gradient level (3,000 ft), the NEXRAD detected 75-kt (39-m/sec)

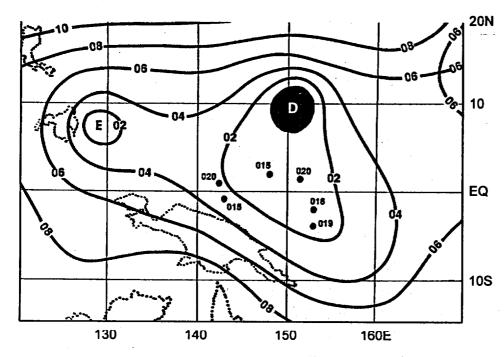


Figure 3-36-2 Sea-level pressure analysis based upon a composite of ship observations at 040600Z and 041800Z November. Individual ships near the equator with reports of 1002 mb or lower are indicated. D = Dale, E = Ernie, and SLP contours are drawn at 2 mb intervals.

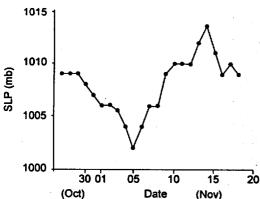


Figure 3-36-3 Time series of the equatorial SLP near 150°E based upon ship observations.

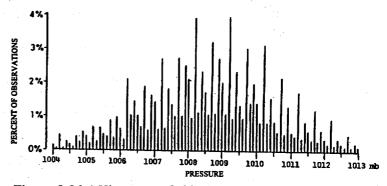
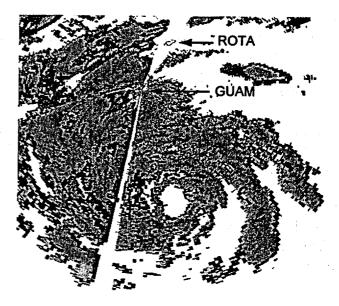
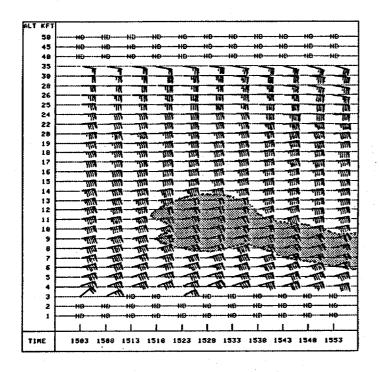


Figure 3-36-4 Histogram of ship SLP reports extracted from the COADS data set in the box bounded by 2°N and 2°S from 148°E to 152°E (adapted from Morrissey, 1988).

Figure 3-36-5 NEXRAD base reflectivity showing the eye, wall cloud and peripheral rain bands of Dale as it nears its CPA to Guam. Guam remained in the dry wedge between the outer rain bands and the eye-wall cloud for an extended period (071458Z NEXRAD base reflectivity product).



winds (not shown in Figure 3-36-6) which correlated well with the peak gusts observed on Guam (Figure 3-36-7). Although the maximum winds in a typical TC are expected to be at the gradient level, NEXRAD coverage of Dale showed they were considerably higher in altitude. Perhaps the lack of deep convection and associated torrential rain were factors in the relatively elevated level of the wind maximum during Dale's passage by Guam.



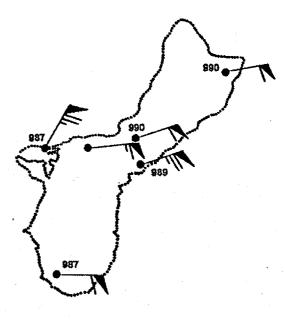


Figure 3-36-6 The NEXRAD velocity azimuth display (VAD) wind profile near the time of Dale's CPA to Guam showing winds of 100 kt (51 m/sec) or more between 6,000 and 12,000 ft (shaded region) (071553Z NEXRAD VAD wind profile product).

Figure 3-36-7 Peak gusts and minimum SLP recorded at several selected sites on Guam during Dale's passage.

c. Dale's digital Dvorak (DD) numbers

The time series of Dale's DD numbers (Figure 3-36-8) peaked at approximately 090600Z with values of approximately T 7.5. After this peak, the DD numbers fell sharply to below T 5.0 by 100000Z. The warning and best-track intensity lag the peak DD numbers by about six hours, and do not reflect the sharp drop in the DD numbers after the peak. As the DD numbers are considered experimental, and are not used operationally, it is not expected that the warning intensity would be strongly tied to them. The DD numbers do, however, often reflect prominent observable changes in the characteristics of the TC. In Dale's case, the rapid drop of the DD numbers after the peak occurred because concentric eye walls formed. At peak intensity, Dale had a well-defined small eye (Figure 3-36-1). When the DD numbers fell, it was because concentric eye walls formed (Figure 3-36-9a, b). The default radius used to define the eye-wall cloud-top temperature in the DD algorithm is 30 nm. This radius fell between the inner and outer eye walls, and resulted in the period of low DD values after the peak. The radius used to define the eye-wall cloud-top temperature is an adjustable parameter on the MIDDAS system, and when set to 10 nm, it was able to measure the inner eye wall. This resulted in DD numbers of about one T number higher than those computed

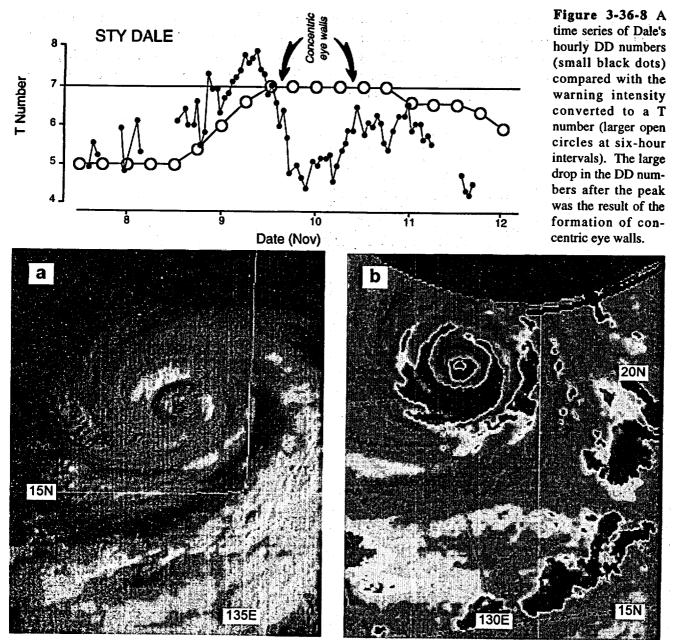


Figure 3-36-9 Dale's concentric eye walls as indicated by (a) visible satellite imagery (092331Z visible GMS imagery), and (b) microwave imagery (110117Z November 85 GHz SSM/I DMSP imagery).

using the default radius during the time when Dale possessed concentric eye walls. The structural changes of Dale show that, though automated, the DD algorithm still requires a satellite analyst to adjust its adaptable parameters and determine the quality of its output.

d. The generation of phenomenal seas in the periphery of a typhoon

While phenomenal surf is common on the eastern shores of Guam when typhoons pass to the south, it is rare that a typhoon produces phenomenal surf on the west side of Guam. Generally, on the north side of a westward moving typhoon, the seas are increased due to the increased wind on that side, but more importantly, due to the artificial fetch that is created as the moving typhoon

keeps up with its own wave train and allows the sea state to rise to its full potential. On the south side of westward-moving typhoons, there is a severe fetch restriction, and the seas can't reach their fully arisen state.

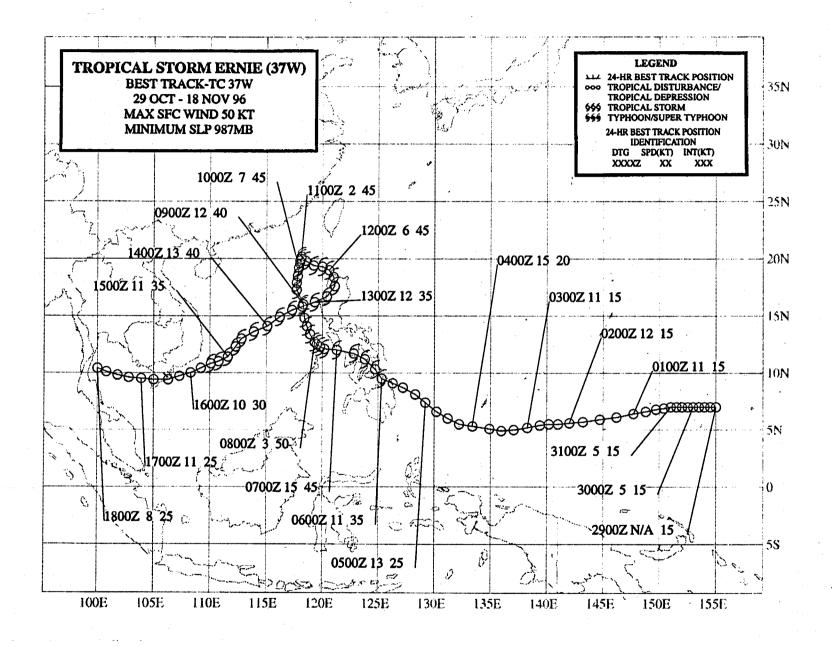
After Dale passed Guam, a very large swell of 20 to 30 feet pounded the western shores of Guam for two days. The wave run-up overtopped 100 ft (30 m) sea cliffs on Orote Point on the west side of Guam (Figure 3-36-10). Such extreme swell from the west is not common on Guam. Even the passage of the large Super Typhoon Yuri only 80-nm south of Guam during November 1991 and the direct eye passage over Guam of the 105-kt (54-m/sec) Omar (1992) did not result in very large westerly swell on Guam. Clearly, some special conditions are required for a typhoon to generate these conditions. Such swell is clearly not directly related to the intensity of the typhoon or even to its size (Yuri was both very intense and very large). It appears that in order for a typhoon to generate phenomenal westerly swell on Guam it must be accompanied by a large region of monsoonal gales extending to its south and west. This was true of Dale and also of the only other typhoon in recent history (Andy, 1989) that was known to have produced phenomenal surf on the west side of Guam. Another phenomenal surf event on the west side of Guam was not produced by a typhoon at all, but by a persistent monsoonal gale area that was associated with a monsoon gyre in the Philippine Sea in 1974.

IV. IMPACT

Dale affected the island of Guam and caused problems for ships at sea. Damage on Guam was mainly caused by high surf, first from the east and later from the west. High surf from the east washed out sections of the coastal road on the southeastern side of the island. Later, surf run-up from the west overtopped 100 ft sea cliffs and damaged Navy housing on Orote Point Naval Activities. Currents and surges inside the reef generated by the west swell also eroded and flooded the beach fronts. Damage estimates for Guam were approximately \$3.5 million. Dale also caused damage in the Pulep Atoll, the Hall Islands and several islands of the Chuuk Atoll. The U.S. Coast Guard provided relief supplies to people on these islands. High seas contributed to the loss of the cattle ship, M/V Guernsey Express, enroute for Japan from Australia. Navy helicopters from Guam, USNS Zeus and Kilauea and U.S. Coast Guard search and rescue worked together to rescue the crew of 18 as the ship was sinking.



Figure 3-36-10 Sea water explodes 100 ft into the air as a wave reflecting off the Orote Point cliff line meets an oncoming breaker (Photo courtesy of Major R. Edson).



TROPICAL STORM ERNIE (37W)

I. HIGHLIGHTS

At the start of the second week of November, four TCs existed simultaneously in the WNP—Ernie, Dale (36W), Tropical Storm (TS) 38W, and Tropical Depression (TD) 39W. Ernie, Dale (36W) and TD 39W formed in the monsoon trough, while TS 38W developed in association with a TUTT cell. After entering the South China Sea, Ernie executed a clockwise loop as it merged with TD 39W. Earlier, while crossing the Philippines, Ernie was responsible for loss of life and extensive property damage.

II. TRACK AND INTENSITY

During the first week of November, a near-equatorial trough formed along approximately 5°N latitude in the WNP. Deep convection associated with this trough consolidated into two distinct systems: the easternmost became Dale (36W) and the westernmost became Ernie. The pre-Ernie tropical disturbance was first mentioned on the 290600Z October Significant Tropical Weather Advisory when satellite imagery and synoptic data indicated that a weak LLCC was associated with an area of persistent deep convection. Development of this disturbance was slow, perhaps hindered by persistent vertical wind shear from the east-northeast, and its transformation into a monsoon depression. Late on 03 November, a small area of deep convection near the core of the monsoon depression persisted; leading to the issuance, valid at 031800Z November, of a TCFA. The first warning on TD 37W followed, valid at 041200Z. Based on satellite intensity estimates, TD 37W was upgraded to Tropical Storm Ernie at 060600Z as the system moved into the central islands of the Philippine archipelago.

On 07 November, Ernie moved into the South China Sea, slowed, and intensified. Satellite imagery indicates that Ernie reached peak intensity of 50 kt (26 m/sec) at 070600Z. As the system reached peak intensity, it made an abrupt turn to the north, perhaps in response to strengthening southwesterly monsoonal flow into Dale (36W) (located to Ernie's east), and also the effects of a binary interaction with TD 39W (which had formed to Ernie's northeast). On 10 November, Ernie subsumed the weakening circulation of TD 39W (Figure 3-37-1) in a merger representing the final stage of a binary interaction (see the Discussion section). After the merger, Ernie executed a clockwise loop which saw the system make landfall in northwestern Luzon before moving back into the South China Sea. As Dale (36W) recurved, Ernie began to move toward the southwest in response to steering influences of a well-entrenched northeast monsoon over the northwestern portion of the South China Sea. In the time span of three and one-half days, Ernie traversed the South China Sea, slowly weakened, and made landfall on the southern tip of Vietnam. The final warning was issued, valid at 170000Z, as the weakened TC moved westward into the Gulf of Thailand and dissipated.

III. DISCUSSION

Merger of Ernie with TD 39W

Ernie and TD 39W underwent a binary interaction that ended in the merger of the two systems. The separation distance between the two systems was always within the 400 nm (740 km) separation threshold noted by Lander and Holland (1993) for TC merger. Though the centroid-relative motion of the two systems shows a clear cyclonic orbit (Figure 3-37-2), only the actual track of TD 39W shows clear signs of orbit. The merger of Ernie with TD 39W was asymmetric in that the smaller TD 39W was sheared and subsumed into the larger circulation of Ernie. Note that even in such cases, the centroid-relative motion of each TC will always be a mirror image of the other's.

IV. IMPACT

In the central Philippines, Ernie was reported to have killed 16 people and caused \$US 4.1 million damage to property.

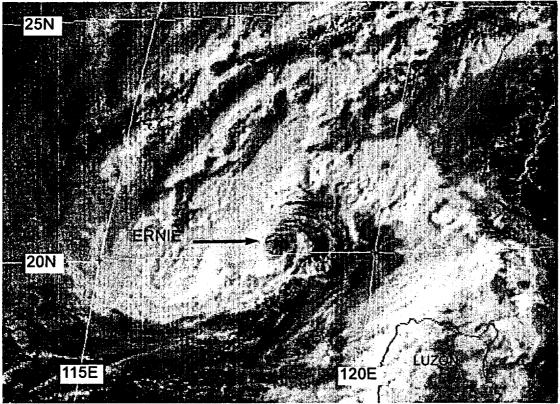


Figure 3-37-1 Tropical Storm Ernie (37W) shortly after its merger with TD 39W. An exposed low-level circulation center is visible (102331Z November visible GMS imagery).

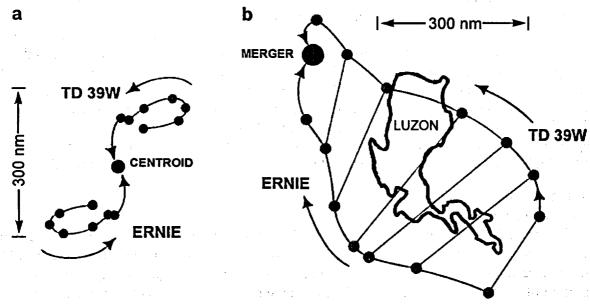
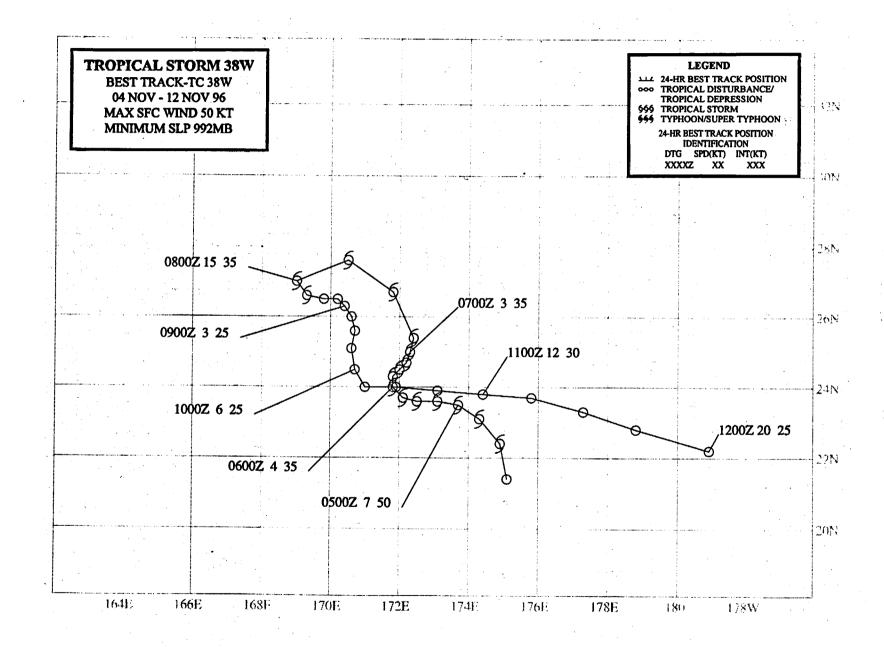


Figure 3-37-2 (a) The complex binary interaction of Ernie with TD 39W is revealed by a diagram of its centroid-relative motion which features a period of anticyclonic relative orbit prior to the period of cyclonic orbit leading to merger. (b) The tracks of these TCs do not as clearly exhibit the properties of the mutual interaction. Dots are at 12-hour intervals beginning at 061200Z November. Merger occurs at 100000Z.



TROPICAL STORM 38W

I. HIGHLIGHTS

Tropical Storm (TS) 38W was the third unnamed WNP TC of 1996 which was considered in real time to have only been a tropical depression, but was determined in postanalysis to have reached tropical storm intensity. TS 38W was unusual in that it developed in association with a very late-in-the-year TUTT cell. During its 8-day life, TS 38W traced a highly erratic 1500 nm (2800 km) track, but it ultimately dissipated only 180 nm (335 km) from where it was first detected.

II. TRACK AND INTENSITY

While Dale (36W) and Ernie (37W) were developing east of the Philippines on 04 November, the tropical disturbance which became TS 38W was first detected as a circulation which formed in direct association with an unusually late-in-the-year TUTT cell. This disturbance was first mentioned on the 040600Z November Significant Tropical Weather Advisory. As cloud organization continued to improve, a TCFA was issued valid at 050600Z. The first warning on Tropical Depression 38W, valid at 060600Z, was prompted by the detection on the ERS-2 scatterometry data of 30-kt (15-m/sec) winds in association with a well-defined LLCC (Figure 3-38-1). In postanalysis, a reassessment of ship, microwave, scatterometer, and conventional visible and infrared satellite data revealed the need to upgrade the peak intensity of the tropical depression to an unnamed tropical storm (see the Discussion). The final warning was issued, valid at 080600Z, when all the deep convection sheared away to the northeast leaving the LLCC completely exposed.

Tropical Storm 38W exhibited a highly erratic track during its life over open water at relatively high latitude near the international date line. The erratic motion featured initial northwestward motion, followed by a counterclockwise loop, and finally (as the system dissipated) a two day period of eastward motion. The end result of the erratic motion was 1500 nm (2800 km) of total distance covered, but an end point only 180 nm (335 km) removed from the place of origin.

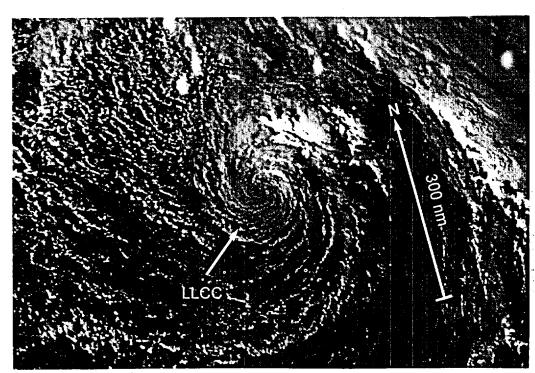


Figure 3-38-1
Tightly wound low-level cloud lines describe the well defined LLCC of TS 38W (060426Z November visible GMS imagery).

III. DISCUSSION

Postanalysis upgrade from tropical depression to tropical storm

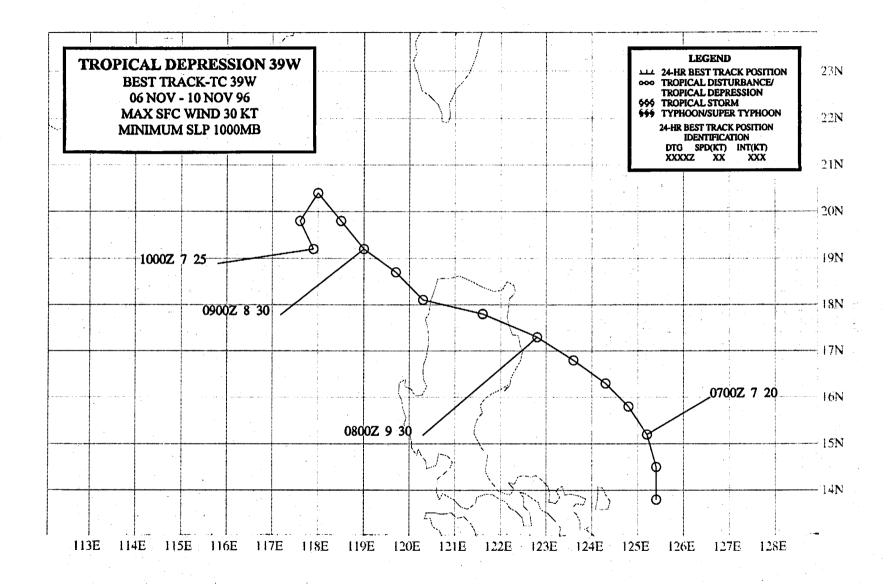
Because of an unconventional structure for a TC (a large well-defined LLCC with most of the deep convection displaced a few hundred kilometers to the northeast — a structure common to many TUTT cell-related TCs, and also to subtropical cyclones) (Figure 3-38-1), the real-time satellite intensity estimates for TS 38W were only 25-30 kt (12-15 m/sec). A ship report at 050000Z with a pressure of 997 mb and a 50-kt (26-m/sec) north-northwesterly wind was considered suspect in real time. In postanalysis however, scatterometer data, microwave and visible satellite imagery were reassessed and judged to be supportive of an upgrade of TD 38W to a tropical storm. At 041200Z and 081200Z, ERS-2 scatterometer data showed a maximum wind speed of 35 kt (18 m/sec) near the LLCC of the system. The SSM/I at 050700Z (Figure 3-38-2) and visible satellite data at 060426Z (Figure 3-38-1) both confirmed that the TC possessed a very well organized and tightly wound LLCC that made plausible the 50-kt (26-m/sec) ship report. Additional features on the satellite imagery, including the "herringbone" pattern of the low-level cumulus extending outward from the LLCC on the northern semicircle indicated near-gale force winds in that area, also supported an increased intensity estimate. Hence TD 38W became TS 38W in postanalysis — the third such occurrence during 1996. Use of new satellite technologies (e.g., scatterometry and microwave imagery) and new understanding of TC structure have made such upgrades more common than in the past. The hope is to refine satellite applications to the point where more accurate assessments can be made in real time.

IV. IMPACT

No reports of damage or injuries were received at the JTWC.



Figure 3-38-2 A mosaic of successive passes of 85-GHz horizontally polarized microwave imager data showing the circulations of Dale (36W) and TS 38W. Note the tight wrap of the low and middle cloud associated with TS 38W (Mosaics of 85-GHz horizontally polarized microwave DMSP imagery - the easternmost pass over TS 38W was dated 050715Z November).



TROPICAL DEPRESSION 39W

Tropical Depression (TD) 39W formed in the monsoon trough which extended eastward from Ernie (37W) across the central Philippines and into the Philippine Sea. When satellite imagery indicated that deep convection was becoming better organized east of Luzon, and satellite and ship reports indicated the presence of a LLCC associated with this area of deep convection, the tropical disturbance which became TD 39W was first mentioned on the 070600Z November Significant Tropical Weather Advisory. As the system tracked northwestward toward Luzon, a TCFA was issued at 080630Z. The TCFA was quickly superseded by the first warning, valid at 080600Z, and was based on ship wind reports of 25 kt (12 m/sec) and sea-level pressure reports near 1000 mb from land stations on the northeast coast of Luzon. The system tracked over the northern tip of Luzon and entered the South China Sea off the northwest tip of Luzon while retaining its peak intensity of 30 kt (15 m/sec). The final warning on TD 39W was issued, valid at 090600Z, as the system began to weaken while undergoing a binary interaction with Ernie (37W) (Figure 3-39-1; also see Figure 3-37-2 in Ernie's summary for a graphical depiction of the binary interaction of TD 39W with Ernie (37W)). On 10 November, the remnants of TD 39W were absorbed by the circulation of Ernie. No reports of damage or injuries were received at the JTWC.

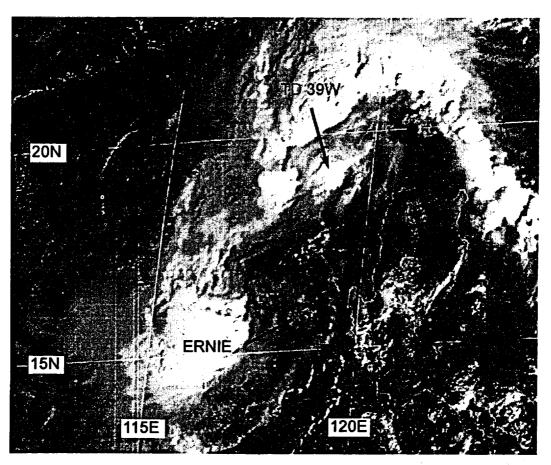
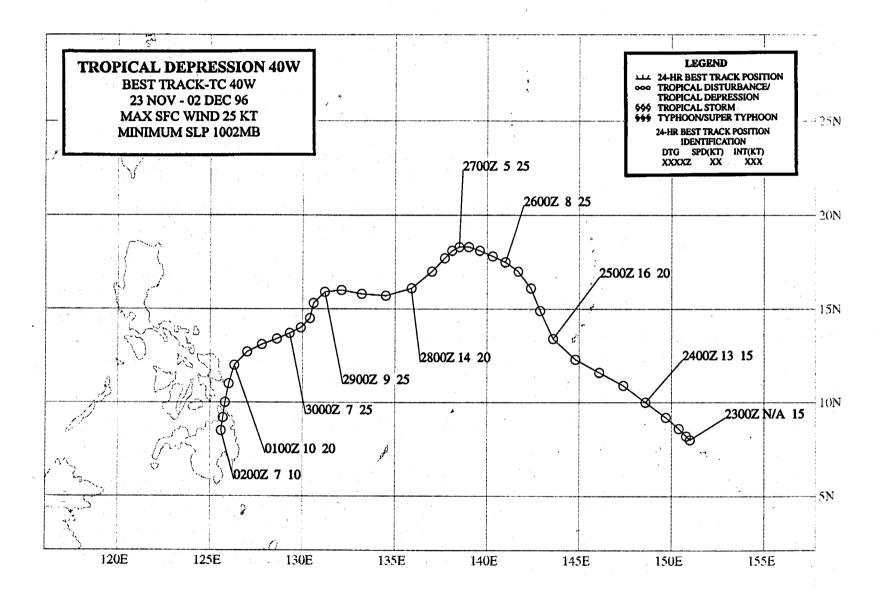


Figure 3-39-1 TD 39W and Ernie (37W) are approaching one another as they undergo a binary interaction (090033Z November visible GMS imagery).



TROPICAL DEPRESSION 40W

After Dale (36W) recurved, and Ernie (37W) moved into the South China Sea, the WNP experienced a break in TC activity. Overall sea-level pressures rose across the WNP tropics and light winds dominated the low latitudes. The break was short-lived, however, as increased convection soon spread across Micronesia and a large monsoon depression developed there. On 23 November, the monsoon depression was centered near Chuuk, and its growing size and increasing organization prompted its first mention on the 231800Z Significant Tropical Weather Advisory. The system drifted northwestward toward Guam, and continued consolidation and organization of the deep convection (Figure 3-40-1) prompted the JTWC to issue a TCFA at 241430Z. This was followed by the first warning on Tropical Depression (TD) 40W, valid at 250000Z. The northwestward motion of TD 40W continued until 27 November when the TC encountered a region of enhanced northeasterly low-level flow associated with an approaching shear line. Interaction with the shear line resulted in a track change to the southwest. As vertical wind shear increased, TD 40W weakened and a "final" warning was issued valid at 270000Z. Two days later, however, deep convection redeveloped within the LLCC and a "regenerated" warning followed, valid at 290000Z. The renewed deep convection did not last long — dissipation ensued and the final warning was issued valid at 010000Z December. On 02 December, the remnants of TD 40W dissipated over Mindanao, but not before unleashing torrential rains on Catanduenas province in the Philippines. Landslides resulting from this heavy precipitation were responsible for at least 14 deaths.

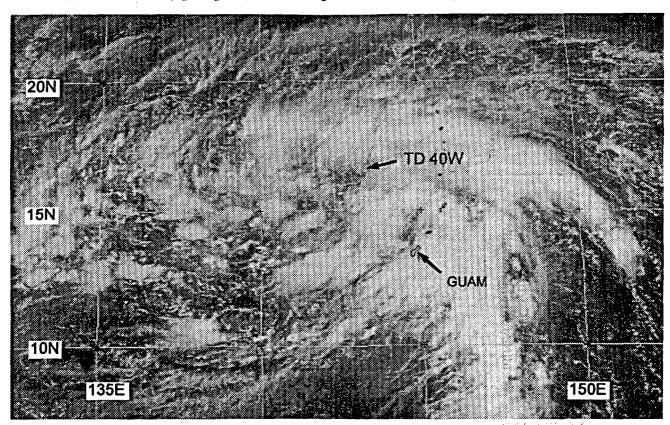
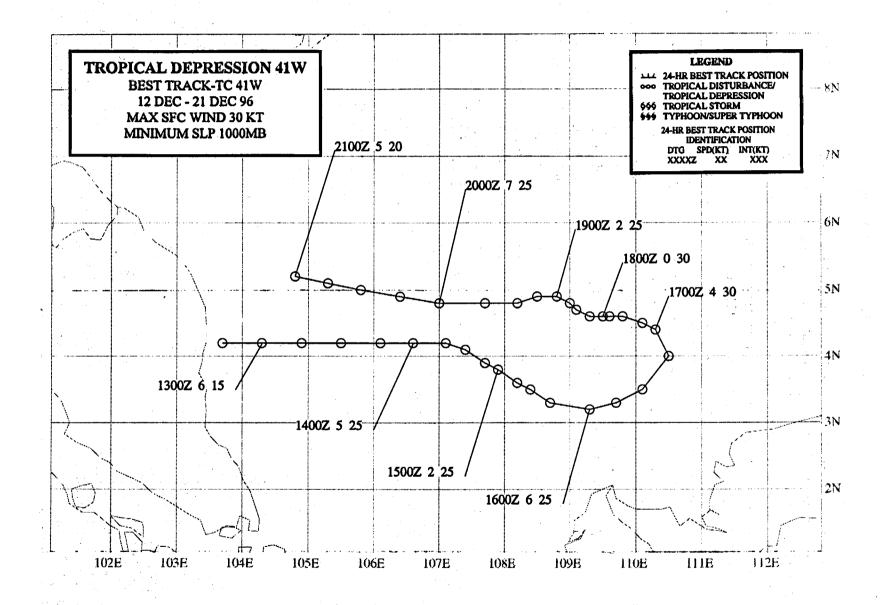


Figure 3-40-1 The monsoon depression which became TD 40W organizes its deep convection near Guam just prior to the first warning (242330Z November visible GMS imagery).



TROPICAL DEPRESSION 41W

After Tropical Depression 40W dissipated over the southern Philippines, there was a break in TC activity in the WNP until 10 December, when an area of deep convection became persistent in the South China Sea. On 13 December, synoptic data indicated a weak LLCC (located east of the Malay peninsula) was associated with this area of deep convection. The system moved eastward along the northern edge of a equatorial westerly wind burst (WWB) (Figure 3-41-1). Based upon synoptic data indicating a well-defined LLCC with maximum sustained wind speeds of 25 kt (13 m/sec), the first warning on Tropical Depression (TD) 41W was issued, valid at 140600Z December. Remarks on the first warning included:

"... The low-level circulation is in an area of convergence between the northeasterly monsoon and an equatorial westerly wind burst. Development is being aided by this strong WWB..." The strength and depth of the WWB to the south of TD 41W appeared to be the dominant steering mechanism, and TD 41W moved eastward until 16 December when the TC approached the northwest coast of Borneo. Here, the TC gradually turned northward and then westward as it came under the steering influence of the northeast monsoon. After doubling back toward the Malay peninsula, the TC continued westward and dissipated on 21 December when located near the location where it formed a week earlier. Strong upper-level easterlies persisted throughout the lifetime of TD 41W, and the resultant vertical wind shear likely limited the intensity of TD 41W to its peak of 30 kt (15 m/sec).

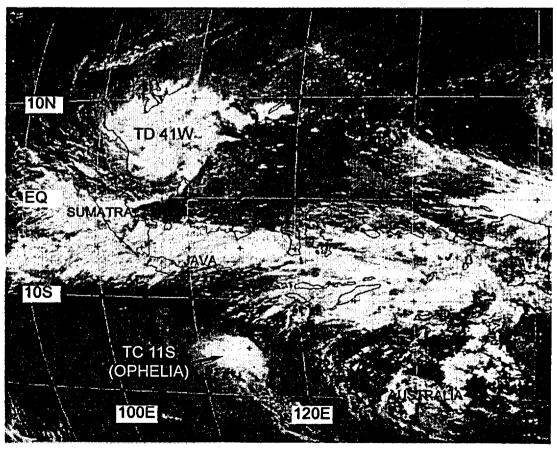
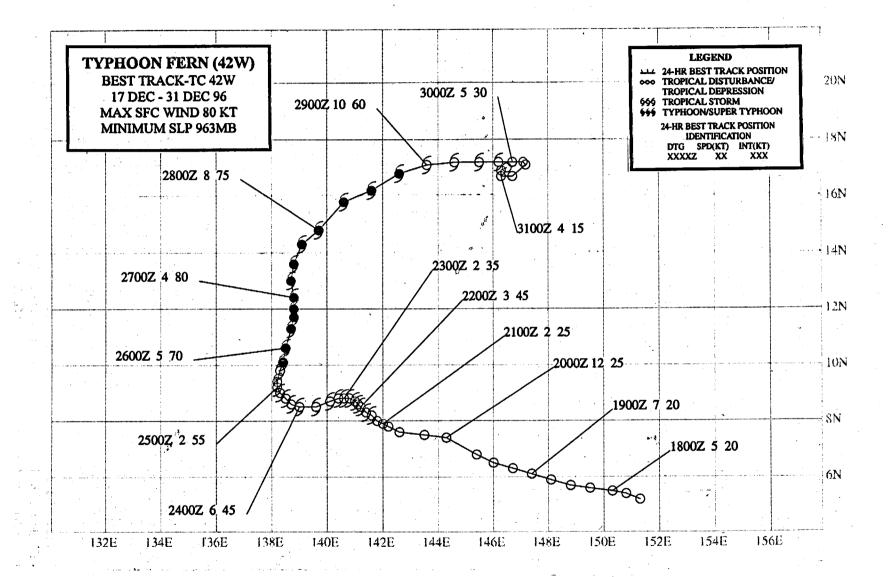


Figure 3-41-1 An extensive east-west cloud band associated with a equatorial WWB separates TD 41W (located in the South China Sea) and TC 11S (Ophelia) located in the Southern Hemisphere to the south of Java (170531Z December infrared GMS imagery).



TYPHOON FERN (42W)

I. HIGHLIGHTS

The last typhoon of 1996, Fern formed at low latitude in association with a strong equatorial westerly wind burst (WWB). While passing over Yap, strong winds and torrential rains caused property damage and personal injury. Eight people were rescued at sea when high seas and winds crippled the cargo vessel, "Mister Bill", while it was enroute from Guam to Yap.

II. TRACK AND INTENSITY

During the second half of December, twin low-latitude monsoon troughs became established between approximately 100°E and 170°E. A band of low-level westerly winds persisted between the two trough axes. A total of five TCs — two in the Northern Hemisphere (Fern and Greg (43W)), and three in the Southern Hemisphere (Ophelia (11S), Phil (12P), and Fergus (13P)) — formed along the respective monsoon trough axis (see Figure 3-43-1 in Greg's (43W) summary).

On 14 December, deep convection began to increase along the equator between approximately 140°E and 160°E in association with an intensifying WWB. A poorly defined LLCC located south-southeast of Guam was noted on the 190600Z December Significant Tropical Weather Advisory. Moving slowly westward, this disturbance remained poorly defined until 21 December when an area of deep convection began to consolidate near a LLCC. Low sea-level pressure (SLP) of 1001 mb and evidence of upper-level divergence over the LLCC (on animated water vapor imagery) prompted the JTWC to issue a TCFA at 211500Z December. The first warning on Tropical Depression (TD) 42W, valid at 211800Z, soon followed based on synoptic data indicating falling SLP in the developing TC (998 mb at 211800Z). Six hours later, on the warning valid at 220000Z, TD 42W was upgraded to Tropical Storm (TS) Fern based on satellite and synoptic data. For the next two days, TS Fern moved slowly westward and remained near minimal TS intensity. On 24 December, the tropical storm turned northward and slowly approached Yap. On Christmas day, Fern passed over Yap (Figure 3-42-1a,b), where SLP fell to 983 mb and a peak wind gust of 63 kt (32 m/sec) was recorded at the Weather Service Office (WMO 91415) (Figure 3-42-2a,b). For several hours peak wind gusts in excess of 50 kt (26 m/sec) on Yap occurred in the westerly flow as Fern moved away to the north. Fern became a typhoon at 251800Z approximately 12 hours after passing over Yap. Continuing to move slowly north for the next three days on the north-oriented portion of its track, Fern reached its peak intensity of 80 kt (41 m/sec) at 261200Z. Reaching peak intensity after turning northward is a common behavior of TCs in north-oriented patterns (see the Discussion). On 28 December, Fern encountered a strong shear line in the low levels and, located within deep-layer westerly steering flow to the north of the subtropical ridge, it began to move toward the east-northeast and weaken. Fern gradually dissipated as it moved eastward along the shear line, and the final warning was issued valid at 300600Z December.

III. DISCUSSION

Peak intensity after recurvature

Most typhoons that undergo classical recurvature (i.e., a roughly "<"-shaped track which features initial steady west-northwestward motion, then a northward turn while slowing, followed by an acceleration toward the northeast) reach peak intensity at, or before, the point of recurvature; where the point of recurvature is identified as that point where the typhoon reaches its westernmost longitude (JTWC 1994). Many TCs do not undergo classical recurvature. Some never recurve, while others move on a track type designated by the Japan Meteorological Agency (JMA) (1976) as north-

oriented. North-oriented tracks occur predominantly during July through October. Carr and Elsberry (1996) found that a TC may undergo north-oriented motion for only a portion of its track — even if some, or most, of the track was of some other type (e.g., straight-moving). A behavior commonly exhibited by TCs undergoing north-oriented motion — and Fern provides a good example — is reaching peak intensity after turning northward or northeastward, but before the speed of translation of the TC significantly increases.

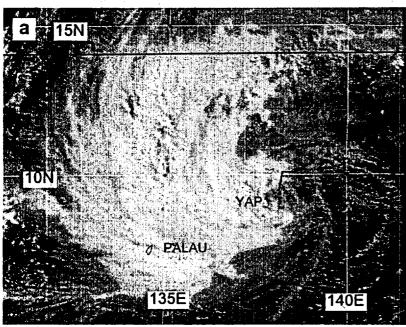
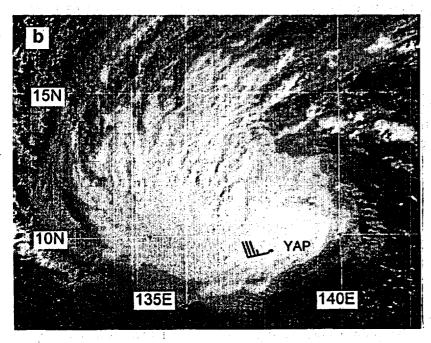


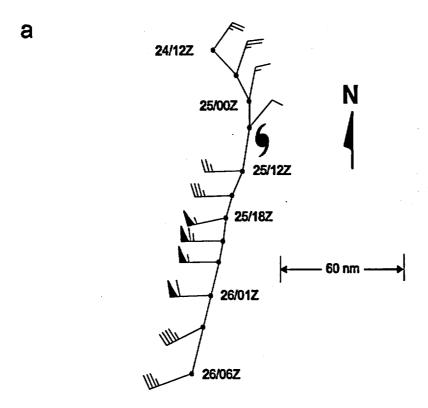
Figure 3-42-1a,b Fern intensifies as it moves directly over Yap: (a) 250531Z December visible GMS imagery, (b) 260631Z December visible GMS imagery.



Fern reached peak intensity while moving northward on the north-oriented leg of its track. It weakened when its speed of translation began to climb as it entered the "accelerating westerlies" regime north of the subtropical ridge. Synoptic regimes, such as "poleward oriented" and "accelerating westerlies", associated with specific TC behavior are described in Carr and Elsberry (1996). (See Carlo's (33W) summary for a discussion of a typhoon that underwent similar intensity changes as it moved on a north-oriented track).

IV. IMPACT

Fern passed directly over the island of Yap. High wind and heavy rain there caused an estimate of nearly US\$ 3 million in damage and clean-up costs. Damage to roads and bridges of US \$1.5 million was the highest single-item total. One person was reported: injured. At sea, a Maltese tanker rescued eight people who abandoned a cargo ship, the "Mister Bill", after it was crippled by high seas while enroute from Guam to Yap. All (including a five-year-old girl) were unharmed. The eight; people had entered a life raft which was spotted by a Navy search-andrescue aircraft.



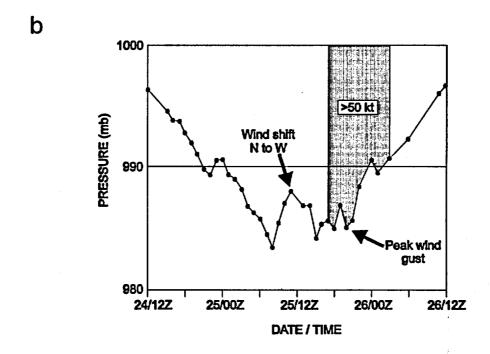
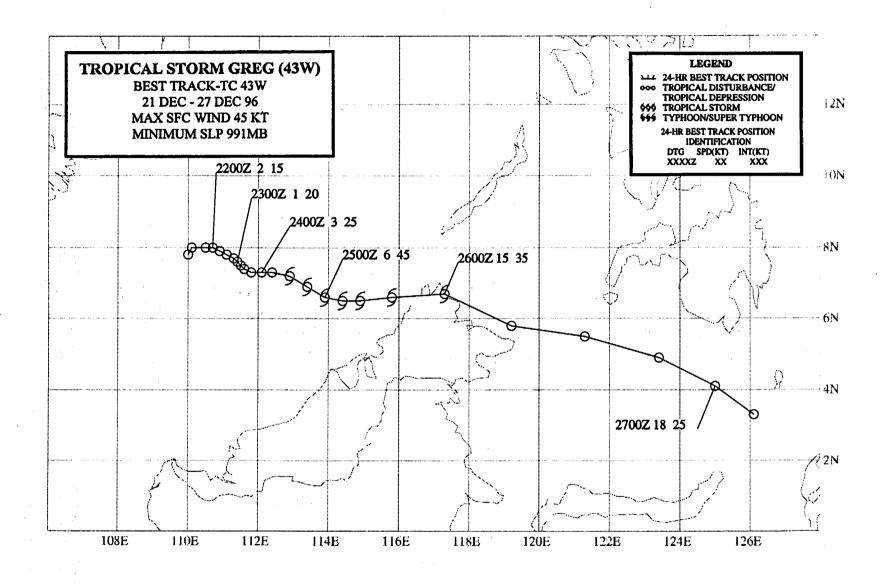


Figure 3-42-2a,b Schematic depiction of (a) peak gusts and (b) sea-level pressure (SLP) recorded at Yap (WMO 91415) during Fern's passage. The peak gust data are recorded with respect to Fern's center. The time series of SLP is based on hourly reports received at the JTWC. Shaded region on SLP diagram indicates wind speeds in excess of 50 kt.



TROPICAL STORM GREG (43W)

I. HIGHLIGHTS

The last significant TC of 1996, Greg was one of the year's most unusual. It formed at low latitude in the South China Sea and moved toward the east-southeast. While passing over the northern tip of Borneo, Greg was responsible for the loss of many lives in the East Malaysian State of Sabah.

II. TRACK AND INTENSITY

During the second half of December, twin low-latitude monsoon troughs became established between approximately 100°E and 170°E. A band of strong low-level westerly winds persisted between the two trough axes. A total of five TCs — two in the Northern Hemisphere (Fern (42W) and Greg) and three in the Southern Hemisphere (Ophelia (11S), Phil (12P), and Fergus (13P)) — formed within these monsoon troughs (Figure 3-43-1).

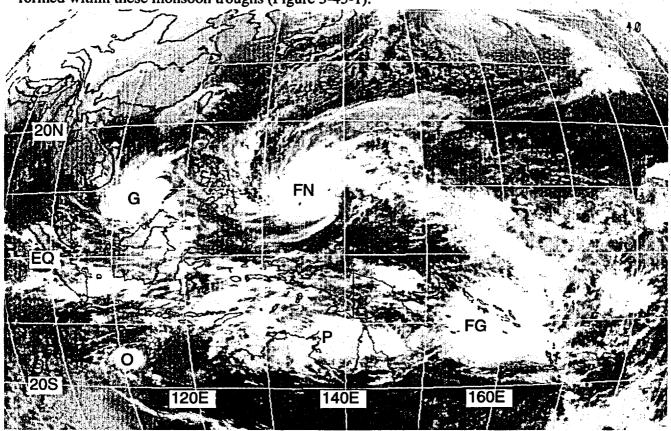


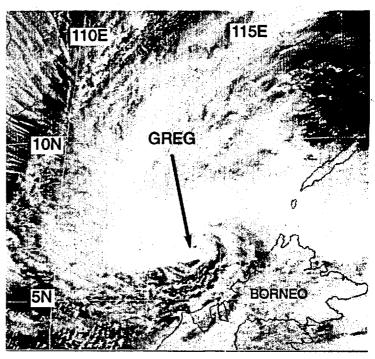
Figure 3-43-1 Five TCs — Greg (G), Fern (FN), Ophelia (O), Phil (P), and Fergus (FG) — lie within twin monsoon troughs (242330Z December infrared GMS imagery).

The tropical disturbance which became Greg was first mentioned on the 210600Z Significant Tropical Weather Advisory when an area of persistent deep convection was observed in the low latitudes of the South China Sea. On 23 December, this area of deep convection began to show signs of becoming better organized. Remarks on the 232100Z Significant Tropical Weather Advisory included:

"[An] area of convection . . . remains near 7N 112E. Animated infrared satellite imagery indicates that the convective organization associated with this system has improved over the past 12 hours in response to an equatorial westerly wind burst. Gradient-level [westerly and southwesterly] winds reported [by stations in East Malaysia are near 30 kt (15 m/sec).] . . ."

JTWC issued a TCFA at 240400Z as visible and microwave satellite imagery indicated that convective organization was improving, and water-vapor imagery supported upper-level divergence over the system. The first warning on Tropical Depression (TD) 43W soon followed, valid at 240600Z. TD 43W was upgraded to Tropical Storm Greg on the warning valid at 250000Z. In postanalysis, however, reanalysis of satellite data determined that Greg most probably became a tropical storm at 241200Z. Continuing to move on a very unusual east-southeastward track, Greg reached a peak intensity of 45 kt (23 m/sec) at 250000Z (Figure 3-43-2) and maintained this intensity until making landfall on the northern tip of Borneo. The final warning was issued, valid at 270600Z, when most of the deep convection associated with the system collapsed as Greg dissipated south of the Philippines.

Figure 3-43-2 Greg at peak intensity of 45 kt (23 m/sec) bears down on the northwest coast of Borneo (250231Z December visible GMS imagery).



III. DISCUSSION

a. On the importance of microwave imagery

During the night of 24 December, as Greg (then TD 43W) was moving east-southeastward toward the northern tip of Borneo, a DMSP satellite passed over the system at 241452Z. Microwave imagery from this pass (Figure 3-43-3) indicated that a well-organized curved band of deep convection accompanied the LLCC. DMSP passes outside of the range of the Guam ground station are received several hours time-late at the JTWC via the MISTIC system. This imagery was used in postanalysis to upgrade Greg to a tropical storm earlier than indicated on the warnings. Though received late, the microwave imagery was nevertheless used to help support the real-time upgrade of Greg to a tropical storm at 250000Z.

b. Greg's unusual east-southeastward motion

Greg's east-southeastward motion from near 8°N 110°E to near 3°N 126°E was very unusual. TCs which form within (or move into) the South China Sea late in the year are often blocked from moving west by well-established northeasterly monsoon flow. Such TCs often remain quasi-stationary or move southwestward and dissipate. Greg formed in the SCS when an unusual large-scale wind pattern dominated the region: a belt of low-level westerly winds existed in equatorial latitudes between twin monsoon troughs (i.e., one north, the other south of the equator). With the Northeast Monsoon blocking its motion to the west, it is hypothesized that the strong westerly winds to the south of Greg provided the flow asymmetry responsible for its eastward motion. This factor, plus the existence of the large circulation of Fern (42W) to Greg's northeast were cited on prognostic reasoning messages as possible sources of the east-southeastward movement of Greg.

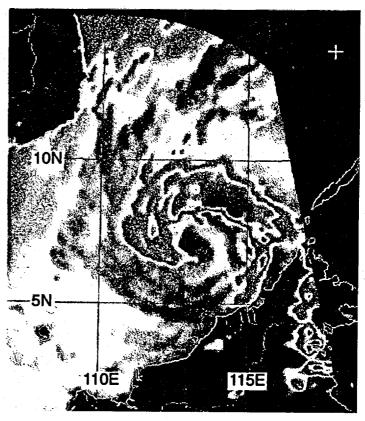


Figure 3-43-3 A well-defined spiral band of deep convection, wrapping almost one complete turn from tip to tail around Greg's LLCC, helped to support the postanalysis upgrade of the timing of tropical storm intensity (241452Z December horizontally polarized 85 GHz SSM/I DMSP imagery).

IV. IMPACT

Greg was responsible for loss of life and extensive damage to property in the East Malaysian State of Sabah (located on the northwest coast of Borneo). At least 124 lives were reported lost with another 100 reported missing primarily due to flooding from torrential rains. In Kota Kinabalu, the capital of the State of Sabah, high wind scattered billboards and other debris, and broke windows in the 30-story government building.

3.2 NORTH INDIAN OCEAN TROPICAL CYCLONES

In 1996, eight significant tropical cyclones occurred in the North Indian Ocean. Five of these were in the Bay of Bengal and three in the Arabian Sea (Table 3-5). Spring and fall in the North Indian Ocean are periods of transition between major climatic controls, and the most favorable seasons for tropical cyclone activity. This year was no exception

(Table 3-6). The total number, eight, was three over than the 22-year average of five. Eight also tied with the total in 1987, however 1992 still holds the record, 13.

The best track composite is shown in Figure 3-9. There are four cyclones of typhoon intensity (a record) — the most intense being TC 07B. The track of TC 08B is unusual due to its length and large clockwise loop in the Bay of Bengal.

					•				
٠		-			NUMBER OF		-		
TROPICAL					WARNINGS	MAXIMUM S	URFACE	ESTI	MATEI
CYCLONE	PERIOD	OF	WA	RNING	ISSUED	WINDS-KT	(M/SEC)	MSLP	(MB)
01B	07 MA	Y -	08	MAY	6	40	(21)	99	4
02A	11 JU	N -	11	JUN	4	40	(21)	99	4
03B	02 JU	N -	17	JUN	20	45	(23)	98	8*
04A	10 JU	N -	19	JUN '	8	65	(33)	97	2*
05A	. 22 OC	T -	26	OCT	15	65	(33)	97	6
	28 OC	т -	31	OCT	15				
06B	25 OC	т -	29	OCT	16	45	(23)	99	1 !
07B	03 NO	v -	07	NOV	16	115	(59)	92	7
08B	28 NO	V -	06	DEC	35	75	(39)	96	7
			T	OTAL	135				

The criteria used in Table 3-6 are as follows:

- 1. If a tropical cyclone was first warned on during the last two days of a particular month and continued into the next month for longer than two days, then that system was attributed to the second month.
- 2. If a tropical cyclone was warned on prior to the last two days of a month, it was attributed to the first month, regardless of how long the system lasted.
- 3. If a tropical cyclone began on the last day of the month and ended on the first day of the next month, that system was attributed to the first month. However, if a tropical cyclone began on the last day of the month and continued into the next month for only two days, then it was attributed to the second month.

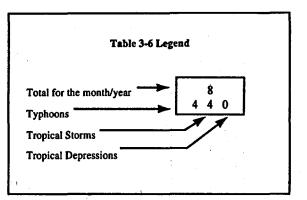


Table	3-6	DIS	TRIBUT	ION OF	NORTH	INDI	N OCE	N TROI	PICAL (YCLON	S FOR	1975-1	996		
YEAR	<u>JAN</u>	FEB	MAR	APR	MAY	<u>Jun</u>	JUL	AUG	<u>SEP</u>	OCT	NOV	DEC	I	OTAI	L <u>S</u>
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1977	0	0	0	0	1	1	0	0	0	1	0	2		5	
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1978	0	0	0	0	1	0	0	0	0	1	2	0	_	4	_
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1979	000	000	0 000	0 000	1 100	1 010	0 000	0 000	2 011	1 010	2 011	0 000		7	2
1980	0	0	0	0	0	010	0	000	011	010			1		2
1900	000	000	000	000	000	000	000	000	000	000	1 010	1 010	0	2	0
1981	0	0	0	0	0	0	0	0	1	0	1	1	U	3	U
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1982	0	0	0	0	1	1	0	0	0	2	1	0		5	•
1302	000	000	000	000	100	010	000	000	000	020	100	000	2	3	0
1983	0	0 -	0	0	0	0	0	1	0	1	1	0		3	U
1703	000	000	000	000	000	000	000	010	000	010	010	000	0	3	0
1984	0	0	0	0	1	0	0	0	0	1	2	0	v	4	v
-50.	000	000	000	000	010	000	000	000	000	010	200	000	2	2	0
1985	0	0	0	0	2	0	0	. 0	0	2	1	1	2	6	٠
	000	000	000	000	020	000	000	000	000	020	010	010	0	6	0
1986	1	0	0	0	0	0 -	0	0	0	0	2	0	•	3	•
	010	000	000	000	000	000	000	000	000	000	020	000	0	3	0
1987	0	1	0	0	0	2	0	0	0	2	1	2	-	8	•
	000	010	000	000	000	020	000	000	000	020	010	020	0	8	0
1988	0	0	0	0	0	1	0	0	0	1	2	1		5	
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1992	0	0	0	0	1	2	1	0	1	3	3	2		13	
1000	000	000	000	000	100	020	010	000	001	021	210	020	3	8	2
1993	0	0	0	0	0	0	0	0	0	0	2	0		2	_
1004	000	000	000	000	000	000	000	000	000	000	200	000	2	0	0
1994	0	0	1	1	0	1	0	0	0	1	1	0		5	
1005	000	000	010	100	000	010	000	000	000	010	010	000	. 1	4	0
1995	0 000	0	0	0	0	0	0	0	1	1	2	0		4	^
1006		000	000	000	000	000	000	000	010	010	200	000	2	2	0
1996	0 000	0 000	0 000 -	0	1	3	0	0	0	2	2	0		8	•
/107E-1		000	000	000	010	120	000	000	000	110	200	000	4	4	0
(1975-1 MEAN		0 1	0 1	0.2	0 6	0 6	۸ 1	0 1	0.3	0 0	1 4	n e			
	0.2 3	0.1	0.1	0.2	0.6	0.6	0.1	0.1		0.9	1.4	0.6		4.8	
CASES	3	1	1	4	12	12	1	1	6	19	29	12		101	



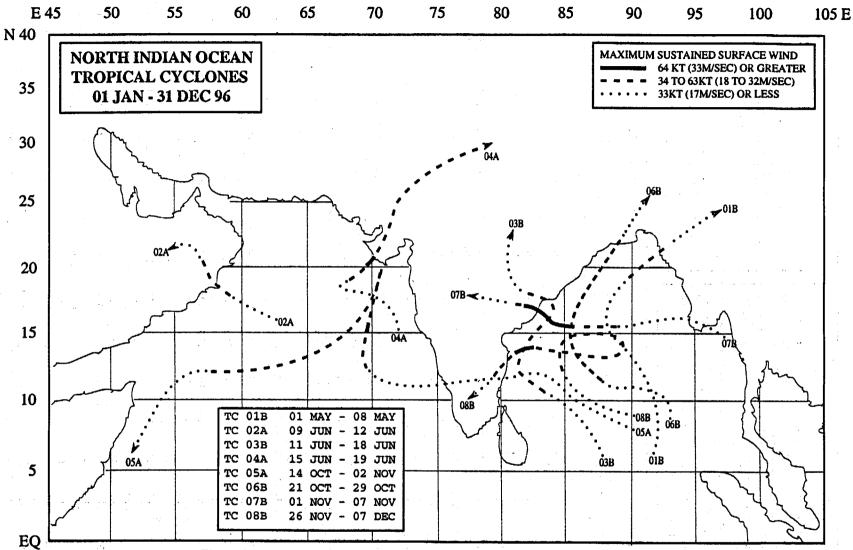
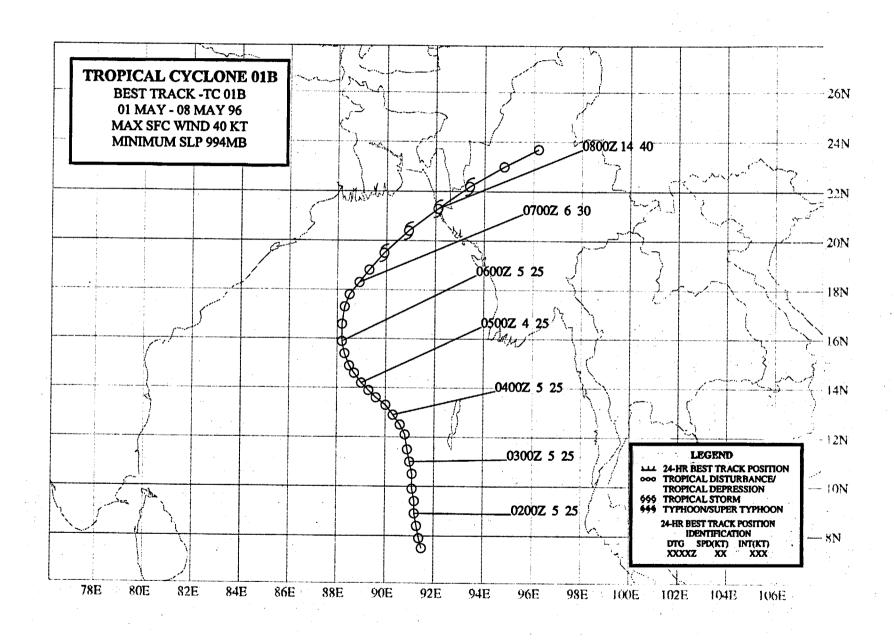


Figure 3-9 Composite of best tracks for North Indian Ocean tropical cyclones for 1996.



TROPICAL CYCLONE 01B

On the first day of May, the tropical disturbance that was to become TC 01B was first observed as a broad area of deep convection in the monsoon trough, 240 nm (440 km) northwest of Sumatra. In the Southern Hemisphere, a "twin" cyclone, which would become Jenna (28S), was also developing (Figure 3-01B-1) in conjunction with the same equatorial westerly wind burst. At 020230Z, the Significant Tropical Weather Advisory was reissued to include both the persistent deep convection associated with pre-TC 01B and the first warning for TC 28S. As the pre-TC 01B disturbance tracked slowly northward, its cloud system organization finally improved to a point where JTWC issued the first TCFA at 051230Z. A second TCFA followed at 061230Z which stated: "... [Although] the [cloud] system organization has changed little from the previous alert ... [it] should improve in the low-shear environment . . [near] the ridge [axis]... Based on DMSP SSM/I and ERS-2 scatterometer data, indicating 30-kt (15-m/sec) winds near the LLCC, JTWC issued the first warning, valid at 070000Z. Intensification continued until TC 01B reached a peak of 40 kt (21 m/sec) at 071800Z — six hours prior to making landfall near Cox's Bazar. Cox's Bazar (WMO 41992) experienced a maximum sustained wind of 40 kt (21 m/sec) and a minimum sea-level pressure of 993 mb. The cyclone dissipated over the mountainous terrain of Myanmar less than a day later. The JTWC received no reports of death or significant damage.

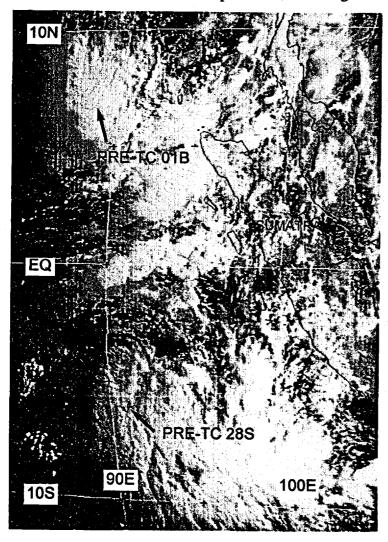
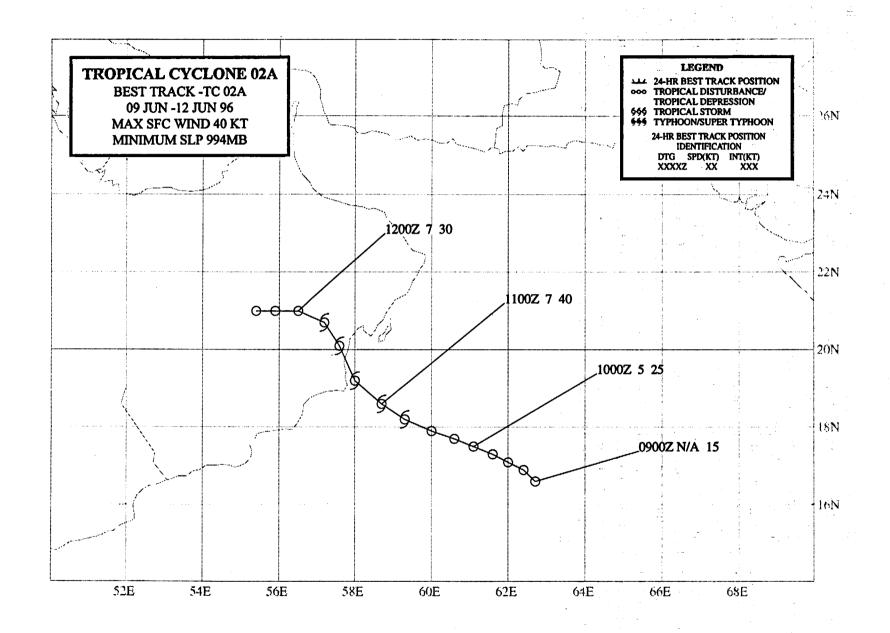


Figure 1-01B-1 The "twin" cyclones — pre-TC 01B and TC 28S — consolidate near the equator (020031Z May visible GMS imagery).



TROPICAL CYCLONE 02A

The second of eight 1996 North Indian Ocean cyclones, TC 02A was the first of three to occur in the Arabian Sea. The tropical disturbance which became TC 02A was initially observed as an area of poorly organized convection in the northwestern Arabian Sea 800 nm (1480 km) northeast of Somalia. Because the convection persisted, the Significant Tropical Weather Advisory was reissued at 092000Z June to include first mention of the disturbance. Based on a combination of infrared, microwave imager, and ERS-2 scatterometer data indicating sustained surface winds of 20-30 kt (10-15 m/sec), a TCFA was issued, valid at 102000Z. Moderate vertical wind shear was expected to slow intensification, however, intensification continued and the first warning was issued, valid at 110000Z. As TC 02A approached the coast, Fahad (WMO 41262), an inland air base on the Arabian Peninsula, recorded maximum sustained 10-minute mean northerly winds of 35 kt (17 m/sec) at 110300Z and Masirah (WMO 41268) recorded a minimum sea-level pressure of 994 mb at 110000Z. The system continued on a west-northwestward track at a peak of 40 kt (21 m/sec) until making landfall 70 nm (130 km) southwest of Al Masirah Island at 110900Z. Figure 3-02A-1 shows TC 02A a few hours before landfall. The final warning was issued, valid at 111800Z, as the remnants of the tropical cyclone dissipated over the desert. No reports of death or significant damage were received.

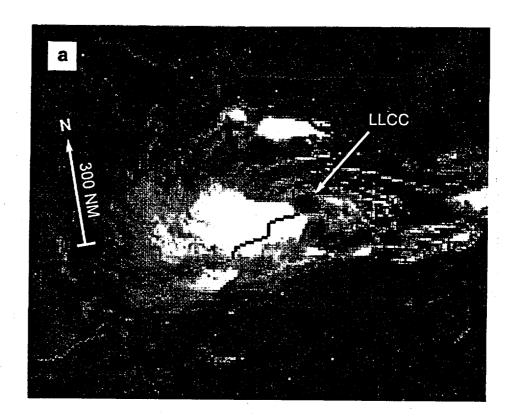
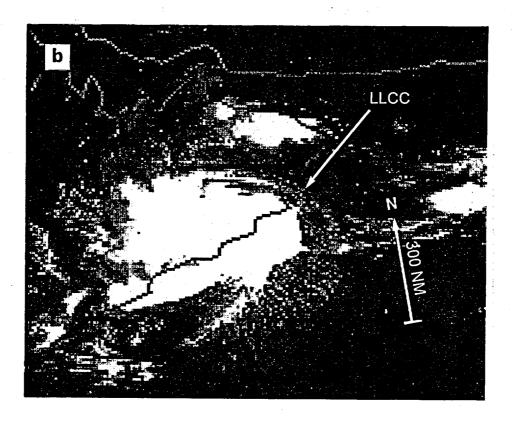
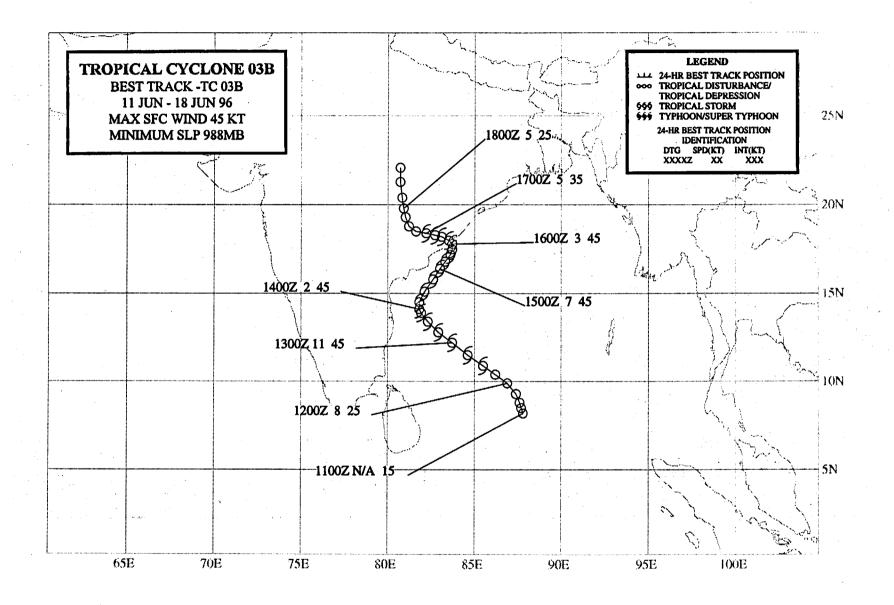


Figure 3-02A-1 TC 02A shortly before making landfall in Oman. Note the significant difference in the cloudiness as viewed in the visible (a) and infrared (b) images. The LLCC is apparent in the visible, but not in the infrared (DMSP imagery courtesy of the Space Physics Interactive Data Resource (SPIDR) Internet site maintained by the National Geophysical Data Center).





TROPICAL CYCLONE 03B

The convection associated with the tropical disturbance that became Tropical Cyclone 03B (TC 03B) consolidated rapidly in the monsoon trough, prompting JTWC to issue a TCFA at 111930Z June. Based on animated satellite imagery, indicating increased convective organization, the first warning was issued, valid at 120600Z. Eighteen hours later, TC 03B reached its maximum intensity of 45 kt (23 m/sec), which it maintained for nearly four days (Figure 3-03B-1). As the cyclone began to weaken, its track changed to a northeastward motion. The cyclone changed to a west-northwest track at 160000Z and made landfall five hours later about 25 nm (46 km) northeast of Vishakhapatnam (WMO 43149) on the Andra Pradesh coast of India. Vishakhapatnam observed 30-kt (10-minute average) (15 m/sec) sustained winds and a minimal sea-level pressure of 987 mb at 160000Z. Waltair (43150) also reported 30 kt (15 m/sec) winds at that time. Once TC 03B was over land, JTWC issued a final warning valid at 170000Z.

Despite the relative weakness of the cyclone, torrential rains accompanied TC 03B inland (Figure 3-03B-2). Flooding from the heavy rains resulted in the loss of 175 lives, more than 3,000 families homeless, and extensive damage. News reports also indicated 270 people (mostly fishermen) were missing.

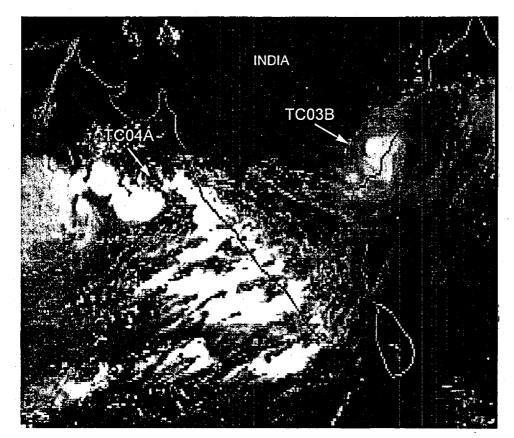
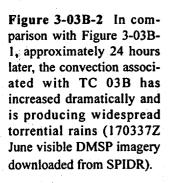
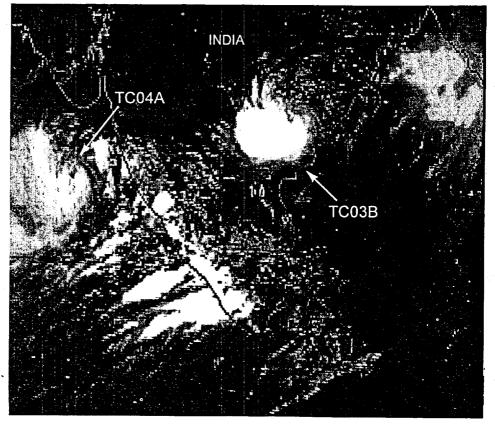
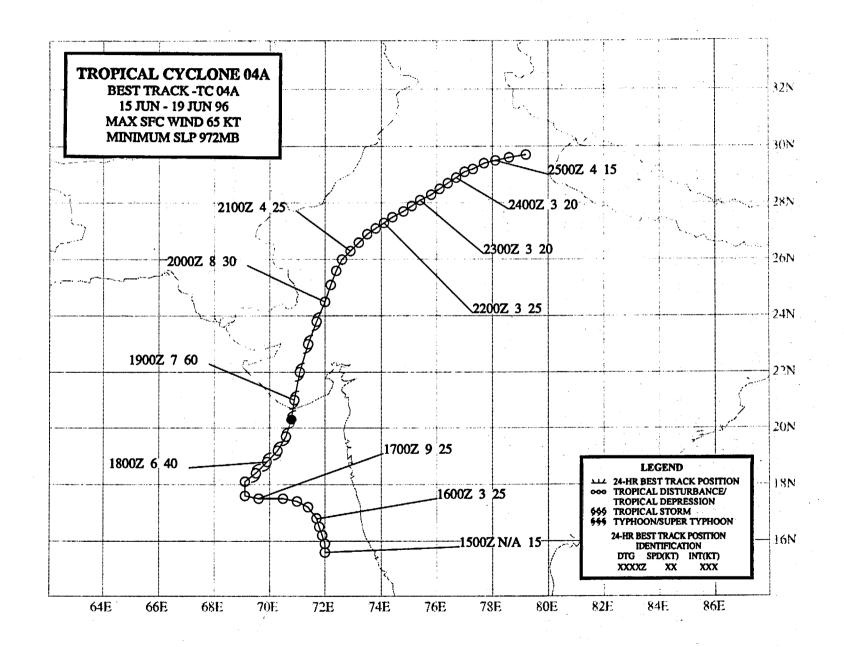


Figure 3-03B-1 As the LLCC of TC 03B nears the coast, deep convection builds inland (160350Z June visible DMSP imagery downloaded from the Space Physics Interactive Data Resource (SPIDR) Internet site maintained by National Geophysical Data Center (NGDC)).







TROPICAL CYCLONE 04A

On 15 June, a day before TC 03B made landfall on the east coast of India, convection associated with the monsoon depression that became TC 04A was first detected on satellite imagery off the west coast of India 210 nm (390 km) south-southwest of Bombay. Although poorly organized, the convection persisted and was first mentioned on the Significant Tropical Weather Advisory at 170700Z. A TCFA was issued at 170730Z June after conventional and microwave satellite data indicated that the wind field had become better organized, and a first warning followed, valid at 171800Z. As TC 04A moved northward and intensified, available Dvorak intensity estimates peaked at 45 kt (23 m/sec). However, synoptic data supported a maximum of 65 kt (33 m/sec) as the cyclone approached the coast. TC 04A made landfall near Diu at 182300Z. Diu is located on the coast of India 330 nm (610 km) southeast of Karachi. Veraval (WMO 42909) reported a minimum sea-level pressure of 974 mb at 182300Z. Rajkot (WMO 42737), 75 nm (139 km) inland, reported a minimum sea-level pressure of 980 mb at 190600Z and 10-minute sustained wind of 46 kt (24 m/sec) at 191200Z. Figure 3-04A-1 shows the 3-hourly surface winds at Rajkot which reflect the passage of the cyclone. JTWC issued the final warning valid at 191200Z, as TC 04A dissipated inland. Figure 3-04A-2 shows convection associated with TC 04A as it moved northward into India.

The maximum storm surge on the southern coast was estimated to be 20 feet (6 meters). Indian government agencies reported 47 people were killed by the cyclone.

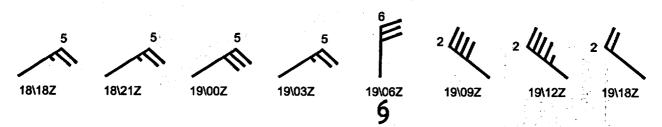


Figure 3-04A-1 Surface wind reports at Rajkot, India (WMO 42737) reflect the passage of TC 04A.

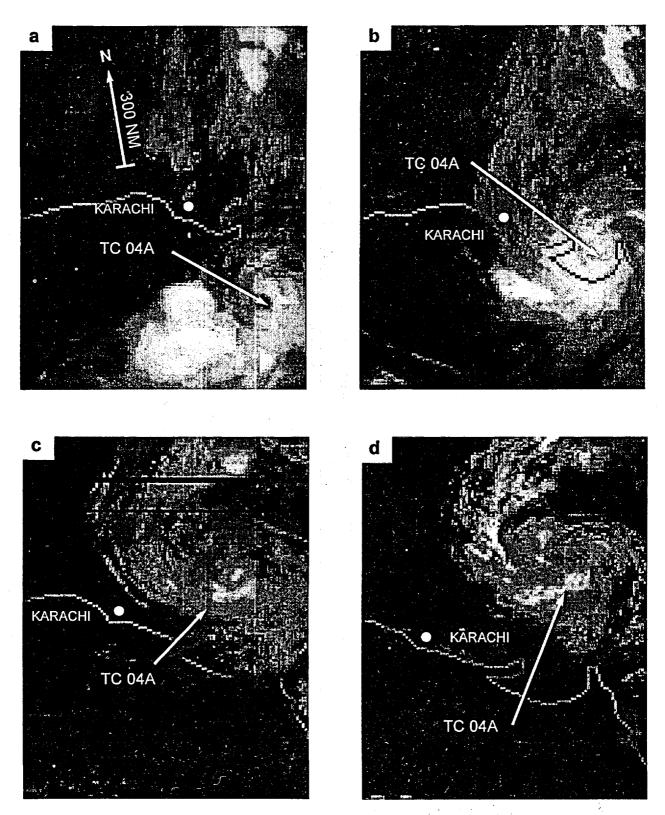
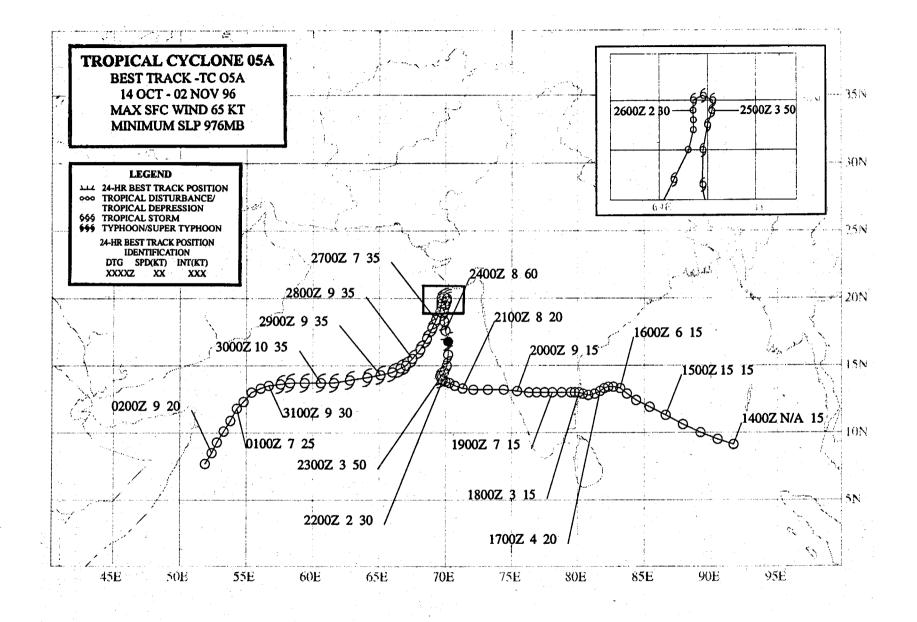


Figure 3-04A-2 Visible imagery — (a) 180507Z June; (b) 190455Z; (c) 200443Z; and (d) 210431Z — covering a 4-day period tracks TC 04A's passage from the Arabian Sea northward into India (Visible DMSP imagery downloaded from SPIDR).



TROPICAL CYCLONE 05A

I. HIGHLIGHTS

Tropical Cyclone 05A (TC 05A), the third Arabian Sea cyclone of 1996, initially started as a mid-October disturbance in the Bay of Bengal, and had one of the most unusual tracks in North Indian Ocean cyclone history. It moved across southern India into the Arabian Sea, stopped, turned north, and intensified. Near 20°N 70°E, the system turned to the southwest, and remained on that track for nine days before dissipating near the Somalia coast. TC-05A was one of the longest-lived cyclones ever in the North Indian Ocean. The Arabian Sea generally averages about one cyclone per year.

II. TRACK AND INTENSITY

TC 05A was first observed as a suspicious area of convection in the southwest Bay of Bengal, about 350 nm (648 km) east of Madras (WMO 43279) on 14 October. After crossing the southern part of the Indian Peninsula and entering the Arabian Sea at speeds ranging from 3-13 kt (5.5-24 km/hr), the disturbance began to organize, and a Tropical Cyclone Formation Alert was issued at 211600Z based on an observed increase in convective curvature and low-level cloud lines in satellite imagery. Shortly thereafter, the disturbance abruptly stopped, began to intensify, and turned to the north near 70°E. The first warning was valid at 221200Z based on a Dvorak T-number of T2.5 (35 kt; 18 m/sec) (Figure 3-05A-1). The system reached an intensity of 65 kt (34 m/sec) (Figure 3-05A-2) on its northward track, then suddenly stopped its northward movement about 50 nm (93 km) south of the southern coast of Gujarat State of northwestern India, after running into strong northeasterly shear. Six hours later, the system began to rapidly weaken from the shear, and took a south-southward track. The final warning was issued at 260000Z, but the system was monitored for regeneration. Figure 3-05A-3 shows the remnants of the cyclone on microwave imagery. These remnants of TC 05A drifted south, away from the region of strong vertical wind shear which had blown away the deep convection. A second Tropical Cyclone Formation Alert was generated at 271600Z when a ship indicated the remnants of TC 05A had a central pressure of 996 mb and 35-kt (18-m/sec) sustained winds. At 280000Z, warnings were resumed for the regenerated cyclone. The system remained, on a southwestward track at minimal tropical-storm intensity. TC 05A finally weakened about two days later, and the final warning was issued at 311200Z while the depression was 60 nm (111 km) northeast of Socotra Island (Figure 3-05A-4).

III. IMPACT

No reports of injuries or damage were received at the JTWC.

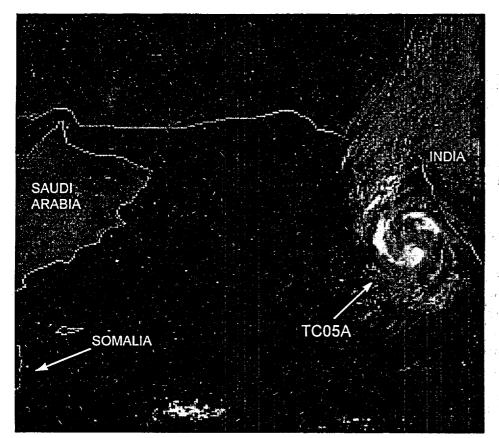
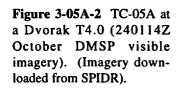
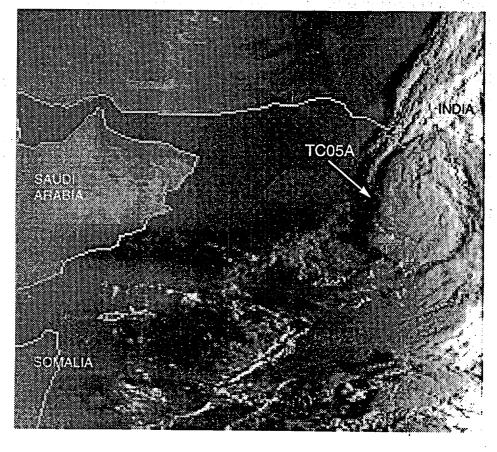


Figure 3-05A-1 TC-05A as deep convection begins to build over the LLCC. (230450Z October DMSP visible imagery). (Imagery downloaded from the Space Physics Interactive Data Resource (SPIDR) internet site maintained by NGDC).

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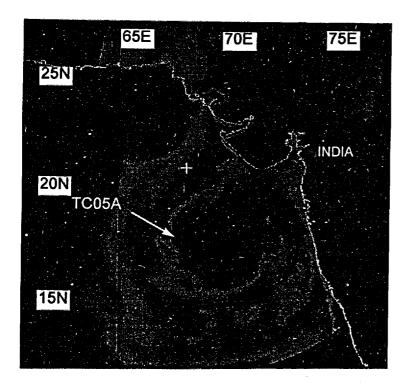
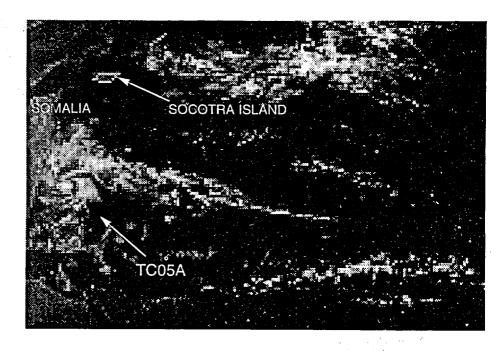
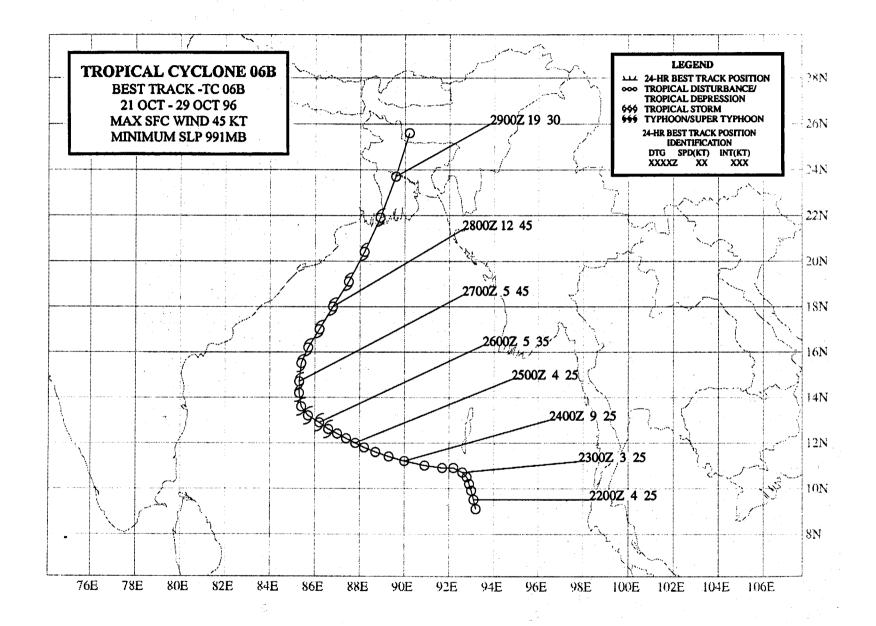


Figure 3-05A-3 The remnants of TC-05A after it had sheared from the convection. The dark circulation signifies low-and-middle-level clouds. (270127Z October DMSP microwave imagery).

Figure 3-05A-4 The remnant LLCC of TC-05A as it approached the Somali coast (020430Z November DMSP visible imagery). (Imagery downloaded from SPIDR).





TROPICAL CYCLONE 06B

The area of poorly organized convection that became Tropical Cyclone 06B (TC 06B) was detected south of the Andaman Islands and first mentioned on the 211800Z October Significant Tropical Weather Advisory. The tropical disturbance was under the influence of strong upper-level easterly wind shear, which resulted in the low-level circulation center being exposed to the east of the deep convection. JTWC issued the first of three TCFAs at 220930Z as the shear appeared to weaken. The anticipated development was delayed, however, and the TCFA was reissued at 230730Z, and again at 240600Z. The convection did finally become better organized and JTWC issued the first warning valid at 250600Z. After recurvature on 27 October, the cyclone accelerated to the northeast. TC 06B made landfall on the heavily populated delta region of West Bengal India near the Bangladesh border at 281800Z (See Figure 3-06B-1). The final warning was issued, valid at 290000Z, as the filling cyclone moved further inland. Heavy rains associated with TC 06B caused flooding, which immobilized much of metropolitan Calcutta. A 9-foot (3-m) storm surge inundated low lying coastal areas in Bangladesh where reports indicated that 14 people were killed, over 2000 people were injured, and 100 fishermen were missing.

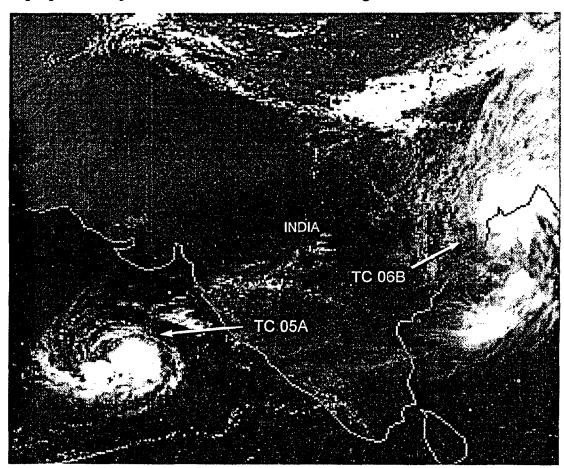
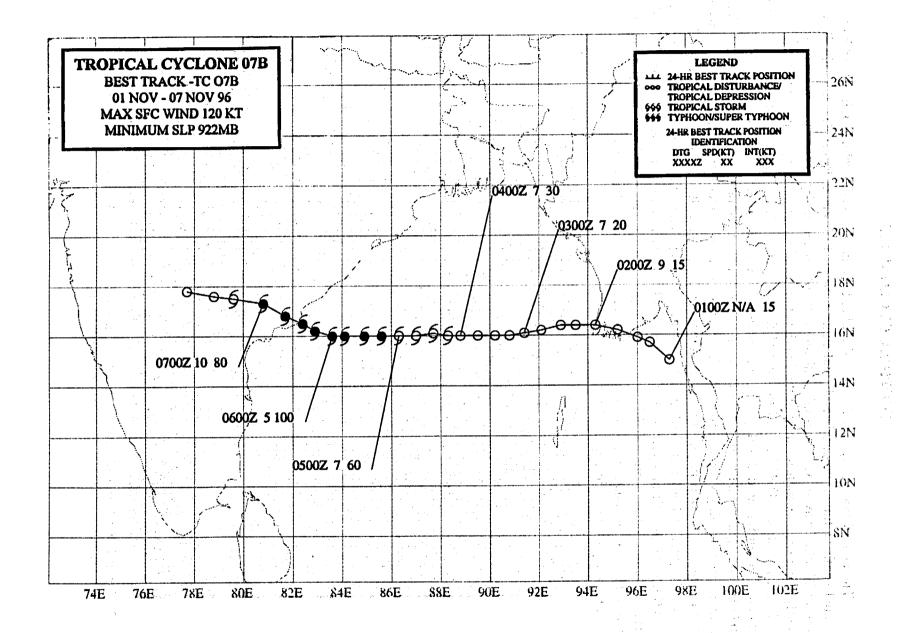


Figure 3-06B-1 TC 06B (upper right) just after making landfall. TC 05A is seen to the west of the India subcontinent (280350Z October visible DMSP imagery).



TROPICAL CYCLONE 07B

As the remnants of TD 43W dissipated over the rugged Malay peninsula, new convection was noted in the Andaman Sea and first mentioned on the 011800Z November Significant Tropical Weather Advisory. Improved convective organization led to the issuance of a TCFA at 030730Z, followed by the initial warning on TC 07B, valid at 031200Z. The system tracked steadily westward under the influence of deep easterly steering flow. Intensification was more rapid than the normal one-T-number per day, and continued until TC 07B peaked at 120 kt (62 m/sec) just before landfall (Figure 3-07B-1) at 061200Z. The development of the wind field associated with this cyclone was evident in the microwave imagery provided by FNMOC on the MISTIC system. After crossing the coast near Kakinada (240 nm (445 km) north-northeast of Madras) at 061300Z, TC 07B weakened as it continued inland. JTWC issued the final warning valid at 070600Z. The cyclone's impact in the coastal areas was significant, and more than 1,000 deaths were attributed to TC 07B. Of these fatalities, 42 passengers were lost when a ferry sank during the storm. More than 1,000 fisherman were reported missing at sea. TC 07B was also responsible for widespread flooding, the destruction of at least 10,000 homes, and the loss of hundreds of thousands of acres of rice crop. More than 250 villages were reported under water and many coastal communities were inundated by 12-foot-high waves. Worst hit was the coastal city of Kakinada where the cyclone dumped 8.8 inches (226 mm) of rain.

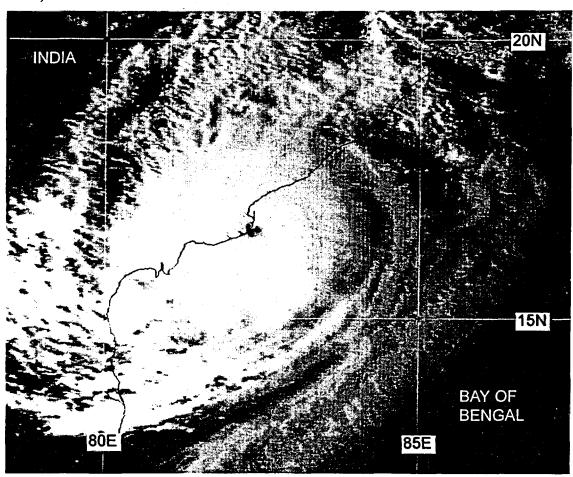
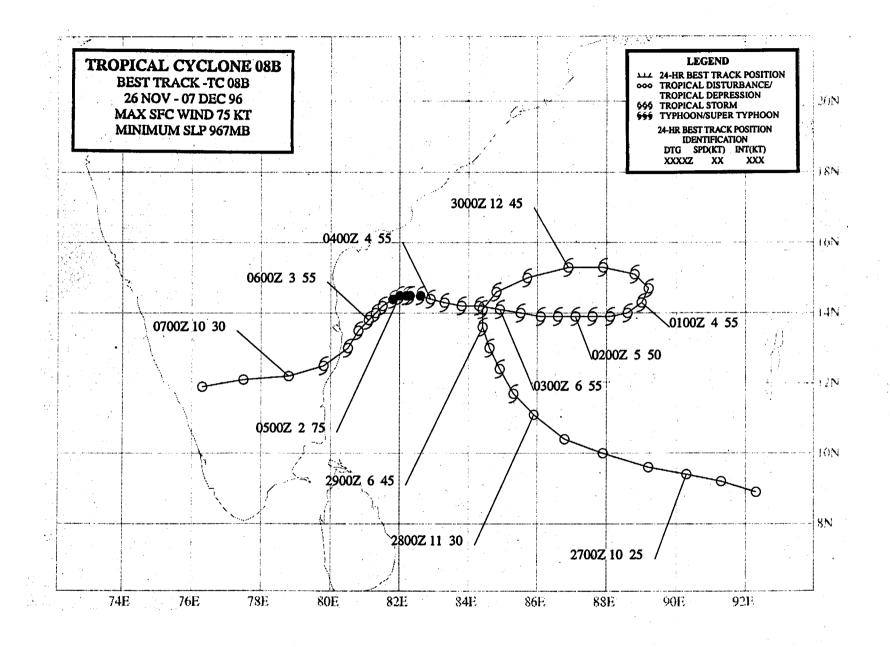


Figure 3-07B-1 TC 07B at peak intensity of 120 kt (62 m/sec)(061024Z November visible GMS imagery).



TROPICAL CYCLONE 08B

I. HIGHLIGHTS

Tropical Cyclone 08B (TC 08B) was unusual for three reasons: 8 days in warning, a 4-day loop, and erratic southwestward movement along the coast of India. Hundreds of lives were probably spared because TC 08B weakened before making landfall.

II. TRACK AND INTENSITY

TC 08B formed in the monsoon trough just south of the Andaman Islands. The persistence of an area of poorly organized convection over a well developed low-level circulation resulted in JTWC's first mention of the tropical disturbance on the 261800Z November Significant Tropical Weather Advisory. As the system slowly developed, JTWC issued the first TCFA at 270130Z. However, a second TCFA was required at 272230Z to reposition the alert area to the west. An increase in overall organization and intensity prompted JTWC to issue the first warning valid at 280600Z. Although TC 08B's initial track was to the west-northwest, the cyclone started a large clockwise loop on 29 November that took four days to complete. Early on 04 December, the system slowed and peaked at 75 kt (39 m/sec). As the cyclone approached the eastern periphery of the blocking high in the low to middle levels over India, strong 50-kt (26 m/sec) upper-level southeasterly winds appeared (Figure 3-08B-1). These features resulted in a track change to the southwest, and increased vertical wind shear weakened the cyclone. By the end of 05 December, the upper and lower levels of the cyclone had become decoupled. The convection was displaced to the northwest and the LLCC moved to the southwest. At 061500Z, TC 08B moved ashore near Pondicherry, about 60 nm (110 KM) south of Madras. The final warning was issued, valid at 061800Z, as the system dissipated over southwestern India.

III. DISCUSSION

a. Longevity

An investigation of Bay of Bengal cyclones since 1972 indicates that no other looping tropical cyclone has taken four days to complete its looping motion. Also, the 8-day period of warning is considered very long, as the average period in warning for Bay of Bengal cyclones is less than four days. Longer warning periods have been noted for cyclones that form in the Bay and move westward in to the Arabian Sea before dissipating.

b. NOGAPS performance

With regard to TC 08B's change of track to the southwest near the coast of India, NOGAPS correctly anticipated the movement as early as 02 December — three days before it actually occurred.

IV. IMPACT

Because TC 08B weakened over water before making landfall, the death toll was very low, 7. There were no reports of significant damage.

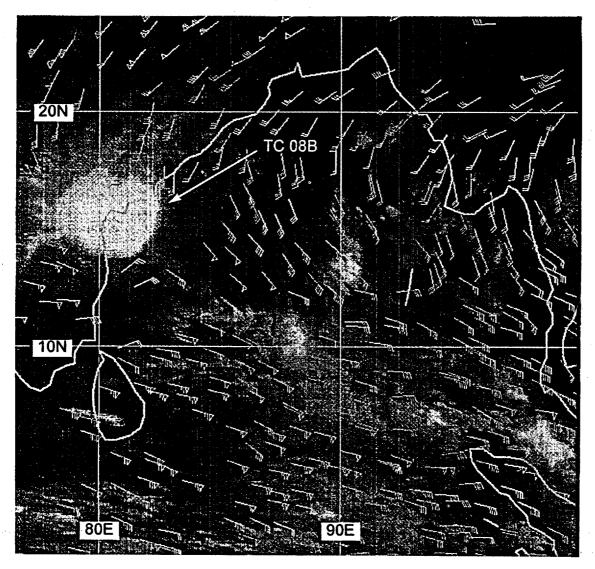


Figure 3-08B-1 Water vapor imagery and upper-level cloud-track winds reveal strong southeasterly winds impinging upon TC 08B (041132Z December water vapor GMS imagery).

4. SUMMARY OF SOUTH PACIFIC AND SOUTH INDIAN OCEAN TROPICAL CYCLONES

4.1 GENERAL

On 1 October 1980, JTWC's area of responsibility (AOR) was expanded to include the Southern Hemisphere from 180° longitude, westward to the coast of Africa. Details on Southern Hemisphere tropical cyclones and JTWC warnings from July 1980 through June 1982 are contained in Diercks et al. (1982), and from July 1982 through June 1984 in Wirfel and Sandgathe (1986). Information on Southern Hemisphere tropical cyclones after June 1984 can be found in the applicable Annual Tropical Cyclone Report.

The NAVPACMETOCCEN, Pearl Harbor, Hawaii issues warnings on tropical cyclones in the South Pacific which are east of 180° longitude. In accordance with CINCPACINST 3140.1W, Southern Hemisphere tropical cyclones are numbered sequentially from 1 July through 30 June. This convention is established to encompass the Southern Hemisphere tropical cyclone season, which primarily occurs from January through April. There are two Southern Hemisphere ocean basins for warning purposes - the South Indian Ocean (west of 135° East longitude) and the South Pacific (east of 135° East longitude) - which are identified by appending the suffixes "S" and "P," respectively, to the tropical cyclone number.

Intensity estimates for Southern Hemisphere tropical cyclones are derived from the interpretation of satellite imagery using the Dvorak (1984) technique and, when available, from surface observations and radar data. The Dvorak technique relates specific cloud signatures to maximum sustained one-minute average surface wind speeds. The conversion from maximum sustained winds to minimum sea-level pressure is obtained from Atkinson and Holliday (1977) (Table 4-1).

4.2 SOUTH PACIFIC AND SOUTH INDIAN OCEAN TROPICAL CYCLONES

The total number of significant tropical cyclones during the 1996 season (1 July 1995 - 30 June 1996; Table 4-2) was 28 which was slightly more than the overall climatological mean of 27 for the previous 16 years as shown in Table 4-3. Looking at the annual variation of Southern Hemisphere Tropical Cyclones by ocean basins (Table 4-4), it becomes apparent that tropical cyclone activity was slightly enhanced in the southern Indian Ocean and Australian regions, and slightly reduced in the South Pacific.

Table 4-1		SUSTAINED 1-MINUTE MEAN
SURFACE	WINDS	AND EQUIVALENT MINIMUM
SEA-LEVEI		RE RELATIONSHIP (ATKINSON
AND HOLLI	DAY, 197	77)
WIND-KT	(M/SEC)	PRESSURE (MB)
30	(15)	1000
35	(18)	997
40	(21)	994
45	(23)	991
50	(26)	987
55	(28)	984
60	(31)	980
65	(33)	976
70	(36)	972
75	(39)	967
: 80	(41)	963
85	(44)	958
90	(46)	954
95	(49)	948
100	(51)	943
105	(54)	938
110	(57)	933
115	(59)	927
120	(62)	922
125	(64)	916
130	(67)	910
135	(69)	906
140	(72)	898
145	(75)	
150	(77)	
155	(80)	879
160	(82)	872
165	(85)	965
170	(87)	858
175	(90)	851
180	(93)	844

The JTWC warned on Southern Hemisphere tropical cyclones for 117 days of the 1996 season. This equates to roughly to 1 out of every 3 days of the 1996 Southern Hemisphere season having a tropical cyclone in active warning status. During 36 of the 117 days there were two or more Southern Hemisphere tropical cyclones in warning status at the same time. An additional 14 days of active warnings were covered

by NAVPACMETOCCEN, Pearl Harbor, 3 days of which multiple tropical cyclones were in warning status.

A chronology of 1996 Southern Hemisphere tropical activity is provided in Figure 4-1. Composites of the tropical cyclone best tracks for the Southern Indian Ocean, the Australian Region, and the South Pacific Ocean, appear in Figures 4-2, 4-3, and 4-4 respectively.

1:23

PROP	ICAL CYCLONE	PERIOD OF WARNING	NUMBER OF WARNINGS ISSUED	ESTIMATED MAX SURFACE WINDS KT (M/SEC)	ESTIMATED MSLP (MB)
)1S	DARYL/AGNIELLE	17 NOV - 25 NOV	17	150 (77)	885
)2S	EMMA*	04 DEC - 06 DEC	4	30 (15)	1000
		09 DEC - 12 DEC	7	40 (21)	994
		14 DEC - 15 DEC	3	30 (15)	1000
)3s	FRANK	07 DEC - 13 DEC	24	115 (59)	927
)4S	GERTIE	18 DEC - 21 DEC	14	75 (39)	967
)5P	BARRY	04 JAN - 07 JAN	7	80 (41)	963
)6S	BONITA	05 JAN - 15 JAN	20	135 (69)	904
)7S	HUBERT/CORYNA	08 JAN - 12 JAN	9	75 (39)	967
8P	TASI.	16 JAN - 19 JAN	0 (6)	45 (23)	991
9P	CELESTE	27 JAN - 30 JAN	7	65 (33)	976
OP	JACOB*	28 JAN - 29 JAN	4	50 (26)	987
	· -	01 FEB - 07 FEB	19	90 (46)	954
15	ISOBEL	28 JAN - 31 JAN	12	45 (23)	991
2 S	-	07 FEB - 09 FEB	5	35 (18)	997
l3P	DENNIS	13 FEB - 18 FEB	11	45 (23)	991
45	DOLORESSE	15 FEB - 19 FEB	9	75 (39)	967
15\$	-	16 FEB - 17 FEB	3	35 (18)	997
16S	EDWIGE*•	22 FEB - 24 FEB	0 (6)	45 (23)	991
	- ,	25 FEB - 29 FEB	0(10)	95 (49)	949
.7s	FLOSSY	27 FEB - 04 MAR	13	115 (59)	927
88	KIRSTY	09 MAR - 12 MAR	13	100 (51)	943
.9P	ETHEL	09 MAR - 13 MAR	10	45 (23)	991
20P	ZAKA	10 MAR - 11 MAR	3	40 (21)	994
21P	ATU	10 MAR - 13 MAR	10	55 (28)	984
22S	GUYLIANNE	20 MAR - 23 MAR	8	35 (18)	997
23P	BETI	21 MAR - 29 MAR	17	105 (54)	938
24S	HANSELLA	03 APR - 10 APR	15	95 (49)	949
25S	OLIVIA	05 APR - 11 APR	19	125 (64)	916
26S	ITELLE	08 APR - 17 APR	19	140 (72)	898
27S	-	16 APR - 19 APR	8	30 (15)	1000
28S	JENNA	01 MAY - 06 MAY	11	60 (31)	980
Fran	d total		321	2.00	1000
• Wa	arnings issued by	NAVPACMETOCCEN (NPMC	C) (22)		
TWC	total		343		

<u>(EAR</u> (1958-197	<u> </u>	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	TOTA
VERAGE*	· ·	-	- ,	0.4	1.5	3.6	6.1	5.8	4.7	2.1	0.5	· <u>-</u>	24.
981	0	: 0	0	1	3	2	6	5	. š	3	1	0	2
982	1	0	0	1	1	3	9	4	2	3	1	0	2
983	1	0	0	1	• 1	3	5	6	3	5	.0	0	2
.984	1	0	0	1	2	5	5	10	Å	2	. 0	0	3
1985	0	0	0	0	1	7	9 ;	9	6	: 3	0	· .	3
1986	0	0	1	0	1	1	9	. 9	6	4	2	. 0	3
987	0	1	0	0	1	3	6	8	3	. 4	1	. 1	2
.988	0	0	0 -	0	2	3	5 .	5	3	1	2	0	2
1989	0	0	0	. 0	2	1	- 5	8 :	6	-4	2	0	2
1990	2	0	1	, 1	• 2	2	4	4.	10	2	1	,0	2
.991	0	0	1	1	1	3	2	5	5	2	1	1	2
.992	0	0	1	1 -	. 2	5	4	11	. 3	2	1	0	3
.993	0	0	1	1	0	5	, 7 -	7	2	2	2	0	2
994	0	0	0	0	2	4	8	4.	9	3	0	0	. 3
.995	0	0	0	: 0	2	2	5 :	4	5	4	0	0	2
.996	0	. 0	0	0	1	, 3	7	6	6	4	1	0	. 2
OTAL	5	1	5	8	24	52	96	105	76	48	15	2	43
VERAGE 1981-199	0.3	0.1	0.3	0.5	1.5	3.3	5.9	6.6	4.7	2.9	0.9	0.1	27.

<u>YEAR</u> (1958–1977)	SOUTH INDIAN (WEST OF 105°E)	AUSTRALIAN (105°E - 165°E)	SOUTH PACIFIC (EAST OF 165°E)	TOTAL
AVERAGE*	8.4	10.3	5.9	24.6
1981	13	8	3	24
1982	12	11	2	25
1983	7	6	12	25
1984	14	14	2	30
1985	14	15	6	35
1986	14	16	.3	33
1987	9	8	11	28
1988	14	2	5	21
1989	12	9	7	28
1990	. 18	8	3 :	29
1991	11	10	1	22
1992	11	6	13	30
1993	10	16	1	27
1994	16	10	4	30
1995	11	7	4	22
1996	13	11	4	28
TOTAL	199	157	81	437
AVERAGE	12.4	9.7	5.1	27.3
(1981-1995)				

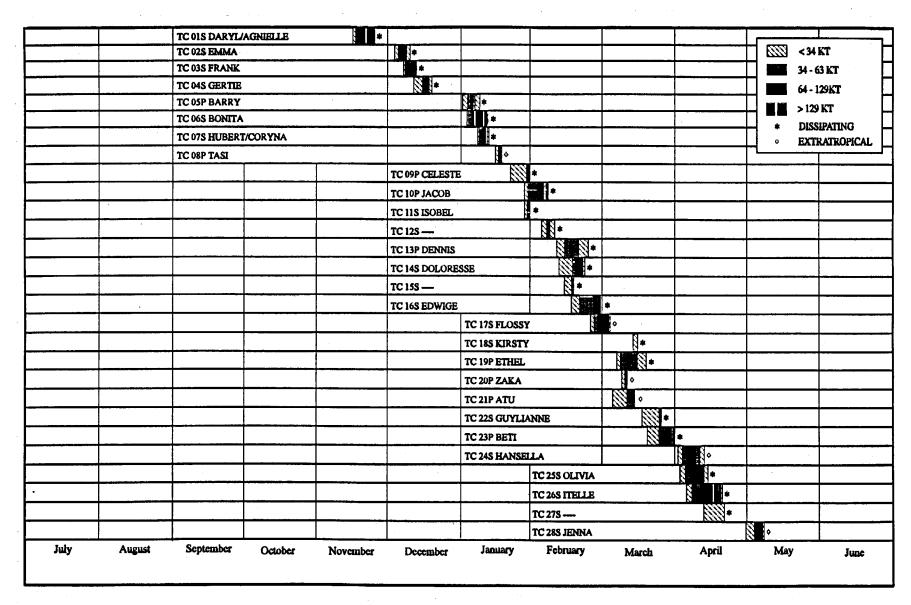


Figure 4-1 Chronology of South Pacific and South Indian Ocean tropical cyclones for 1996 (01 July 1995 - 30 June 1996).

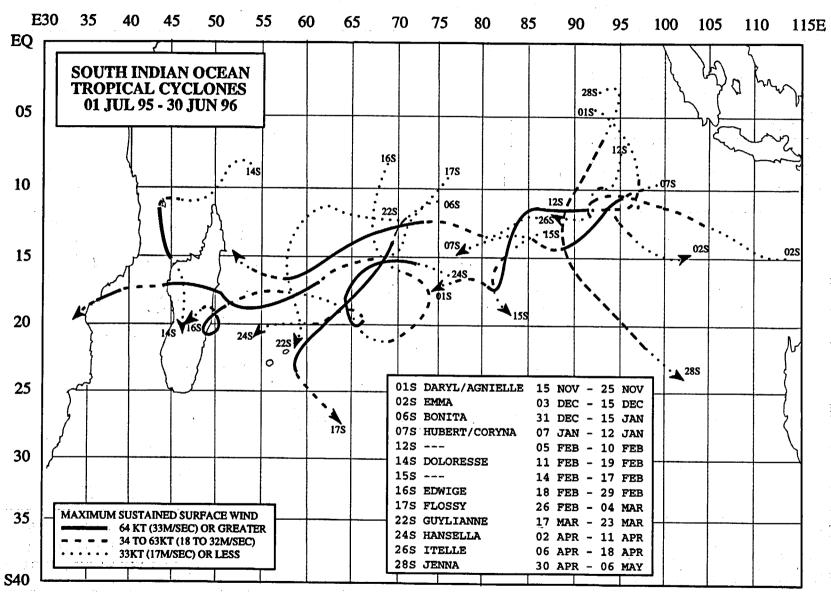


Figure 4-2 Tropical Cyclone best tracks for the South Indian Ocean

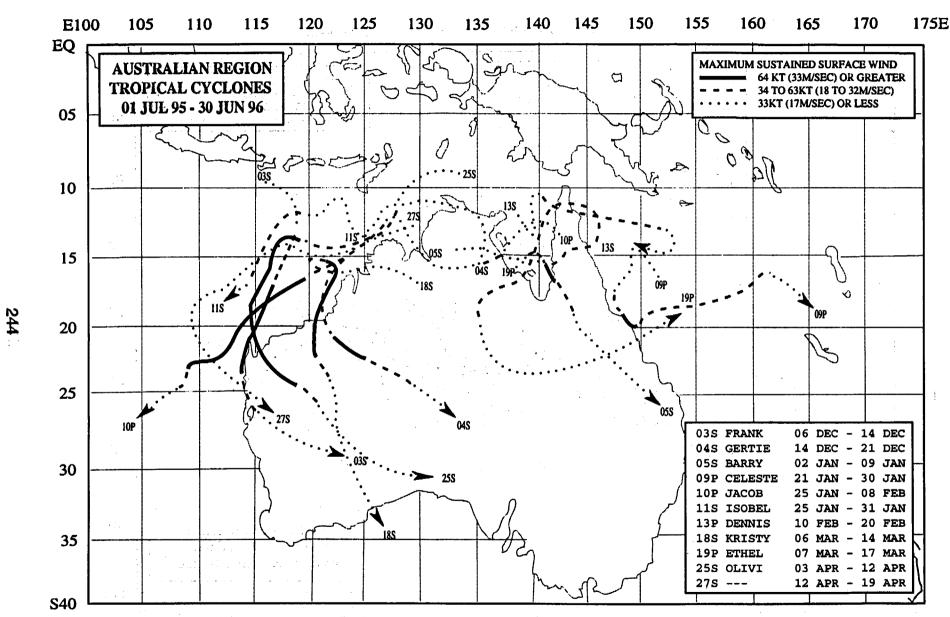


Figure 4-3 Tropical Cyclone Best Tracks for the Australian Region

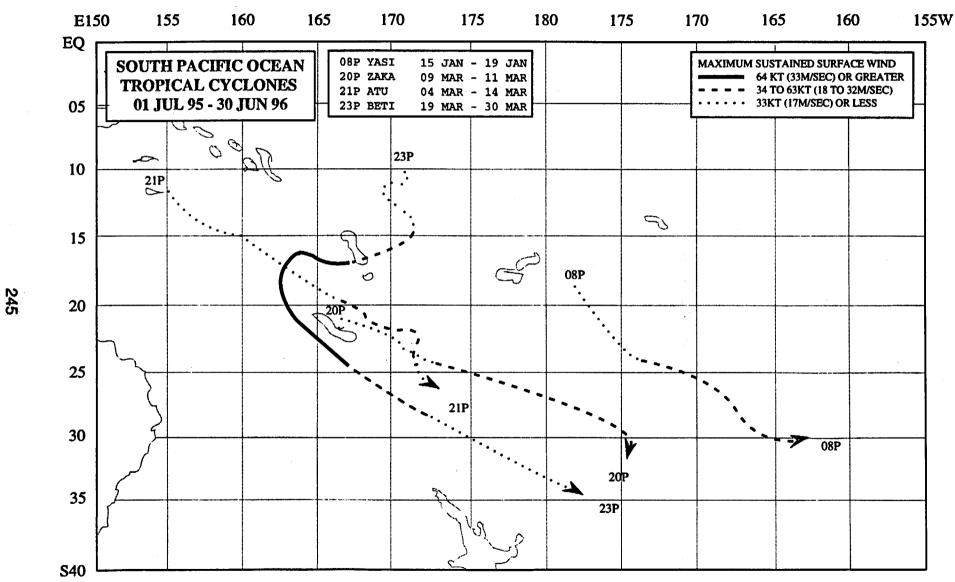


Figure 4-4 Tropical Cyclone Best Tracks for the South Pacific Ocean

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5. SUMMARY OF FORECAST VERIFICATION

5.1 ANNUAL FORECAST VERIFICATION

Verification of warning positions and intensities at initial, 24-, 48- and 72-hour forecast periods was made against the final best track. The (scalar) track forecast, along-track and cross-track errors (illustrated in Figure 5-1) were calculated for each verifying JTWC forecast. These data, in addition to a detailed summary for each tropical cyclone, are included as Chapter 6. This section summarizes verification data for 1996 and contrasts it with annual verification statistics from previous years.

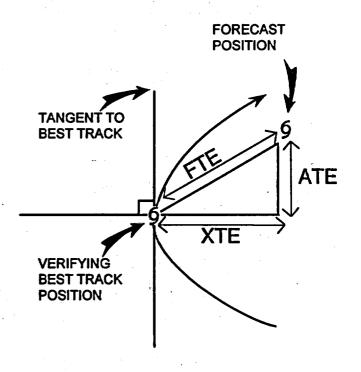
5.1.1 NORTHWEST PACIFIC OCEAN — The frequency distributions of errors for initial warning positions and 12-, 24-, 36-, 48- and 72-hour forecasts are presented in Figures 5-2a through 5-2f. Table 5-1 includes mean track, along-track and cross-track errors for 1981-1996. Figure 5-3 shows mean track errors and a 5-year running mean of track errors at 24-, 48- and 72-hours for the past 20 years. Table 5-2 lists annual mean track errors from 1959, when the JTWC was founded, until the present.

5.1.2 NORTH INDIAN OCEAN — The frequency distributions of errors for warning positions and 12-, 24-, 36-, 48- and 72-hour fore-

Figure 5-1 Definition of cross-track error (XTE), along-track error (ATE) and forecast track error (FTE). In this example, the forecast position is ahead of and to the right of the verifying best track position. Therefore, the XTE is positive (to the right of the best track) and the ATE is positive (ahead or faster than the best track). Adapted from Tsui and Miller, 1988.

casts are presented in Figures 5-4a through 5-4f, respectively. Table 5-3 includes mean track, along-track and cross-track errors for 1981-1996. Figure 5-5 shows mean track errors and a 5-year running mean of track errors at 24-, 48-and 72-hours for the past 20 years.

5.1.3 SOUTH PACIFIC AND SOUTH INDIAN OCEANS — The frequency distributions of errors for warning positions and 12-, 24-, 36-, 48- and 72-hour forecasts are presented in Figures 5-6a through 5-6f, respectively. Table 5-4 includes mean track, along-track and crosstrack errors for 1981-1996. Figure 5-7 shows mean track errors and a 5-year running mean of track errors at 24-, 48-, and 72-hours for the 16 years that the JTWC has issued warnings in the region.



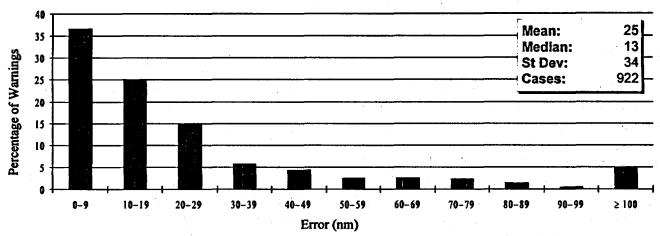


Figure 5-2a Frequency distribution of initial warning position errors (10-nm increments) for western North Pacific Ocean tropical cyclones in 1996. The largest error, 234 nm, occured on Tropical Depression 40W.

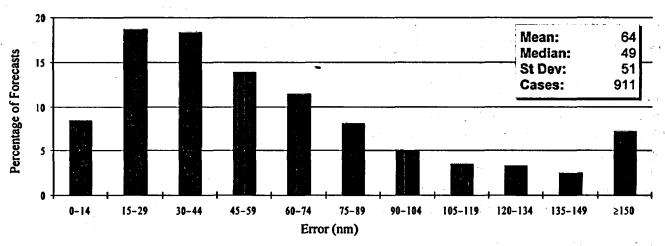


Figure 5-2b Frequency distribution of 12-hour track forecast errors (15-nm increments) for western North Pacific Ocean tropical cyclones in 1996. The largest error, 322 nm, occurred on Tropical Depression 40W.

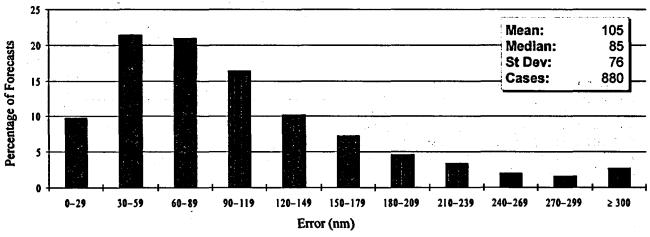


Figure 5-2c Frequency distribution of 24-hour track forecast errors (30-nm increments) for western North Pacific Ocean tropical cyclones in 1996. The largest error, 584 nm, occurred on Typhoon Piper (20W).

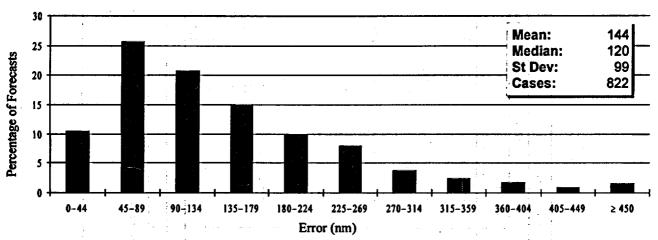


Figure 5-2d Frequency distribution of 36-hour track forecast errors (45-nm increments) for western North Pacific Ocean tropical cyclones in 1996. The largest error, 597 nm, occurred on Typhoon Piper (20W).

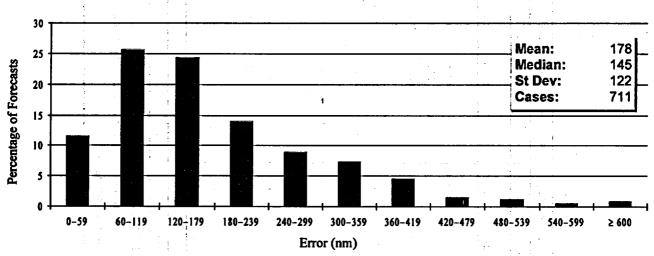


Figure 5-2e Frequency distribution of 48-hour track forecast errors (60-nm increments) for western North Pacific Ocean tropical cyclones in 1996. The largest error, 893 nm, occurred on Typhoon Piper (20W).

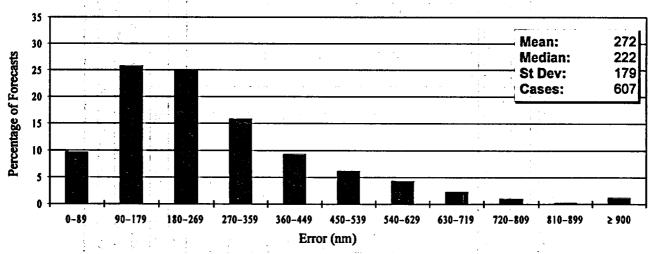
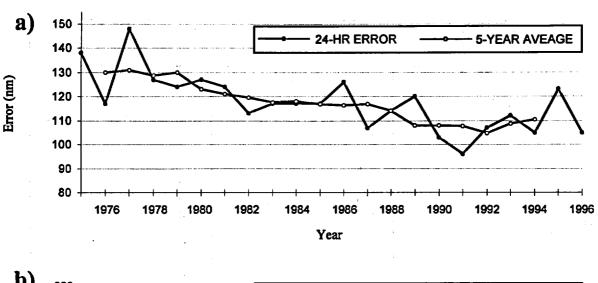


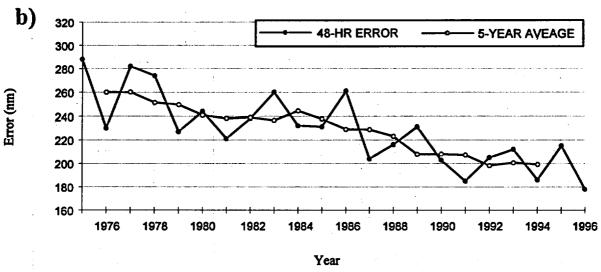
Figure 5-2f Frequency distribution of 72-hour track forecast errors (90-nm increments) for western North Pacific Ocean tropical cyclones in 1996. The largest error, 1129 nm, occurred on Super Typhoon Dale (36W).

				24-H	OUR			48-HC	UR			72-HQ	UR ;	
YEAR	NUMBER OF WARNINGS	INITIAL POSITION	NUMBER OF FORECASTS	TRACK	ALONG	CROSS	NUMBER OF FORECASTS	TRACK	ALONG	CROSS	NUMBER OF FORECASTS	TRACK	ALONG	CROSS
1981	584	25	466	124 :	80	77	348	221	146	131	. 246	334	206	219
1982	786	19	666	113	74	70	532	238	162	142	425	342	223	211
1983	445	16	342	117	76	73	253	260	169	164	184	407	259	263
1984	611	22	492	117	84	64	378	232	163	131	286	363	238	216
1985	592	18	477	117	80	68	336	231	153	138	241	367	230	227
1986	743	21	645	126	85	70	535	261	183	151	412	394	276	227
1987	657	18	563	107	71	64	465	204	134	127	389	303	198	186
1988	465	23	373	114	85	58	262	216	170	103	183	315	244	159
1989	710	20	625	120	83	69	481	231	162	127	363	350	265	177
1990	.794	21	658	103	72	- 60	525	203	148	110	432	310	225	168
1991	835	22	733	96	69	53	599	185	137	. 97	484	287	229	146
1992	941	25	841	107	77	59	687	205	143	116	568	305	210	172
1993	853	26	725	112	79	63	570	212	151	117	437	321	226	173
1994*	1058	24	938	105	76	56	776	186	131	105	631	258	176	152
1995	599	29	539	123	89	67	421	215	159	117	319	325	240	167
1996	922	25	880	105	76	56	711	178	134	89	607	272	203	137
15-YEAR	AVERAGE										•			
1981-1995	712	22	606	113	79	65	478	220	154	125	373	332	230	191

Note: Cross-track and along -track errors were adopted by the JTWC in 1986. Right-angle errors (used prior to 1986) were recomputed as cross-track and along-track errors after-the-fact to extend the data. See Figure 5-1 for the definitions of cross-track and along-track errors.

^{*}Statistics were recalculated to resolve earlier along- and cross-track discrepancies.





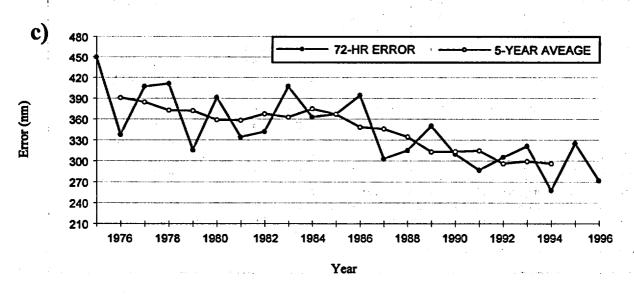


Figure 5-3 Mean track forecast error (nm) and 5-year running mean for a) 24 hours, b) 48 hours and c) 72 hours for the western North Pacific Ocean tropical cyclones for the period 1976 to 1996.

Table 5-2 MEAN FORECAST TRACK ERRORS (NM) FOR WESTERN NORTH PACIFIC TROPICAL CYCLONES FOR 1959-1996

		24	-HOUR			48	-HOUR			72	-HOUR	-
YEAR	TY1	TC	CROSS TRACK ²	ALONG TRACK ²	TY	TC	CROSS TRACK ²	ALONG TRACK ²	TY1	TC	CROSS TRACK ²	ALONG TRACK ²
1959	117*	-			267*							
1960	177*		`		354*				İ			
1961	136				274							
1962	144				287				476			
1963	127				246				374			
1964	133			* *	284	:		•	429		• •	
1965	151				303				418			
1966	136				280				432			
1967	125				276				414			
1968	105				229				337			
1969	111		in the second		237				349			
1970	98	104	and the second		181	190			272	279		
1971	99	111	64		203	212	118		308	317	177	
1972	116	117	72		245	245	146		382	381	210	
1973	102	108	74		193	197	134		245	253	162	1
1974	114	120	78		218	226	157	•	357	348	245	
1975	129	138	84		279	288	181	. ** •	442	450	290	
1976	117	117	71		232	230	132		336	338	202	1.7.25
1977	140	148	83		266	283	157		390	407	228	
1978	120	127	71	87	241	271	151	194	459	410	218	296
1979	113	124	76	81	219	226	138	146	319	316	182	214
1980	116	126	76	86	221	243	147	165	362	389	230	266
1981	117	123	77	80	215	220	131	146	342	334	219	206
1982	114	113	70	74	229	237	142	162	337	341	211	223
1983	110	117	73	76	247	259	164	169	384	405	263	259
1984	110	117	64	84	228	233	131	163	361	363	216	238
1985	112	117	68	80	228	231	138	153	355	367	227	230
1986	117	121	70	85	261	261	151	183	403	394	227	276
1987	101	107		. 71	211	204	127	134	318	303	186	198
1988	107	114	58	85	222	216	103	170	327	315	159	244
1989	107	120	69	83	214		127	162	325	350		265
1990	98	103	70	81	191	203	138	162	299	310	211	242
1991	93	96	53	69		185	97	137	298	286		229
1992	97	107	59	77	194	205	Υ	143	295	305		210
1993	102	112	63	79	205	212	117	151	320	321		226
1994+	9,6	105	56	76	172	186	105	131	244	258	152	176
1995	105	123	89	67	200	215	159	117	311	325	240	167
1996	85	105	56	76	157	178	89	134	252	272	137	203

^{1.} Forecasts were verified for typhoons when intensities were at least 35kt (18m/sec).

^{2.} Cross-track and along-track errors were adopted by the JTWC in 1986. Right angle errors (used prior to 1986) were recomputed as cross-track errors after-the-fact to extend the data base. See Figure 5-1 for the definitions of cross-track and along-track.

^{*} Forecast positions north of 35° north latitude were not verified.

⁺Statistics were recalculated to resolve earlier along- and cross-track discrepancies.

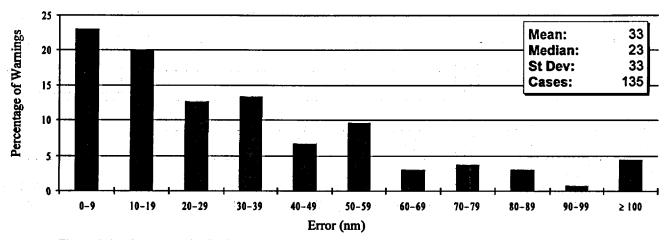


Figure 5-4a Frequency distribution of initial warning position errors (10-nm increments) for North Indian Ocean tropical cyclones in 1996. The largest error, 175 nm, was on Tropical Cyclone 06B.

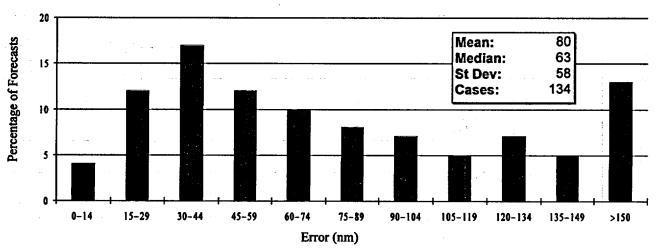


Figure 5-4b Frequency distribution of 12-hour track forecast errors (15-nm increments) for North Indian Ocean tropical cyclones in 1996. The largest error, 290 nm, was on Tropical Cyclone 06B.

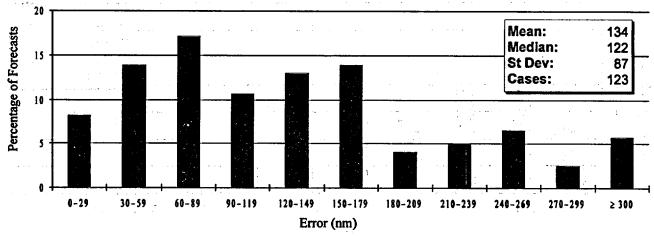


Figure 5-4c Frequency distribution of 24-hour track forecast errors (30-nm increments) for North Indian Ocean tropical cyclones in 1996. The largest error, 397 nm, was on Tropical Cyclone 08B.

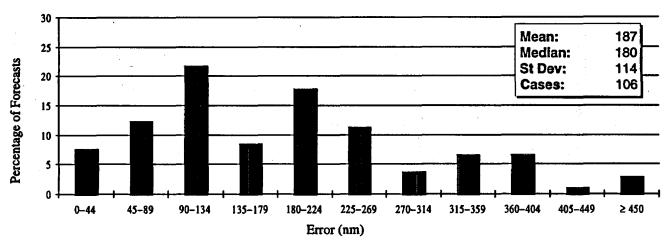


Figure 5-4d Frequency distribution of 36-hour track forecast errors (45-nm increments) for North Indian Ocean tropical-cyclones in 1996. The largest error, 483 nm, was on Tropical Cyclone 06B.

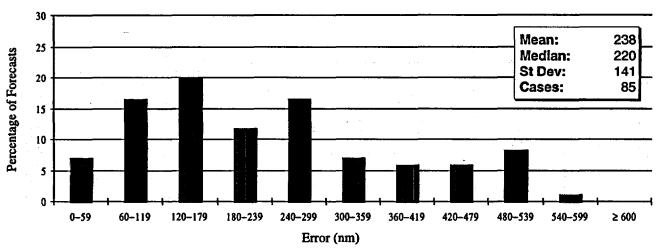


Figure 5-4e Frequency distribution of 48-hour track forecast errors (60-nm increments) for North Indian Ocean tropical cyclones in 1996. The largest error, 578 nm, was on Tropical Cyclone 08B.

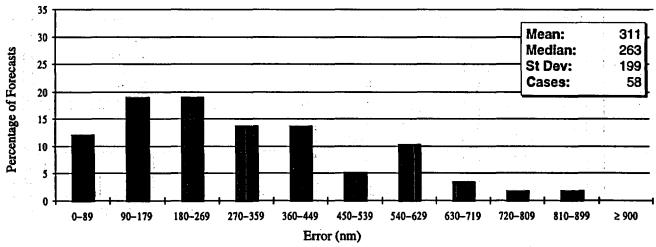
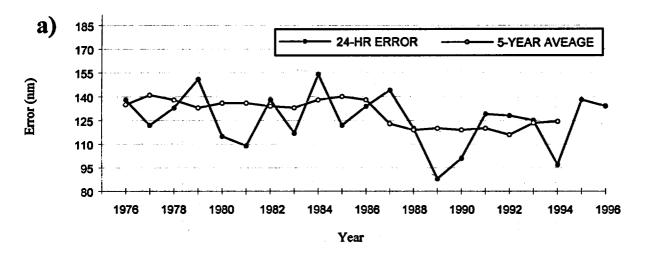
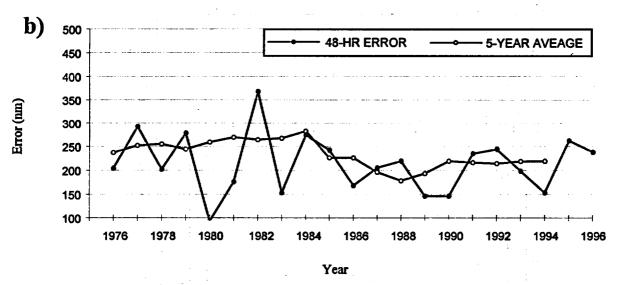


Figure 5-4f Frequency distribution of 72-hour track forecast errors (90-nm increments) for North Indian Ocean tropical cyclones in 1996. The largest error, 875 nm, was on Tropical Cyclone 08B.

				24-H0	UR			48-HO	JR			72-HO	UR	
YEAR	NUMBER OF WARNINGS	INITIAL POSITION	NUMBER OF FORECASTS	TRACK	ALONG	CROSS	NUMBER OF FORECASTS	TRACK	ALONG	CROSS	NUMBER OF FORECASTS	TRACK	ALONG	CROSS
1981	41	28	29	109	76	63	2	176	120	109	5	197	150	111
1982	55	35	37	138	110	68	. 17	368	292	209	7	762	653	332
1983	18	38	7	117	90	50	18	153	137	53	0			
1984	67	33	42	154	124	67	20	274	217	139	16	388	339	121
1985	53	31	30	122	102	53	8	242	119	194	0			
1986	28	52	16	134	118	53	7	168	131	80	5	269	189	180
1987	83	42	54	144	97	100	25	205	125	140	21	305	219	188
1988	44	34	30	120	89	63	18	219	112	176	12	409	227	303
1989	44	19	33	88	62	50	17	146	94	86	12	216	164	111
1990	46	31	36	101	85	43	24	146	117	67	17	185	130	104
1991	56	38	43	129	107	54	27	235	200	89	14	450	356	178
1992	191	35	149	128	73	86	100	244	141	166	62	398	276	218
1993	36	27	28	125	87	79	20	198	171	. 74	12	231	176	116
1994	60	25	44	97	80	44	28	153	124	63	13	213	177	92
1995	54	30	. 47	138	119	58	32	262	247	77	20	342	304	109
1996	135	33	123	134	94	80	85	238	181	127	58	311	172	237
15-YEAF	R AVERAGE													
1981-199	5 58	33	42	123	95	62	24	213	156	115	14	291	224	144

Cross-track and along-track errors were adopted by the JTWC in 1986. Right angle errors (used prior to 1986) were recomputed as cross-track and along-track errors after-the-fact to extend the data base. See Figure 5-1 for the definitions of cross-track and along-track errors.





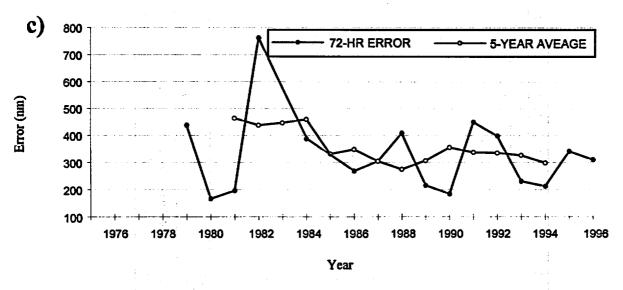


Figure 5-5 Mean track forecast error (nm) and 5-year running mean for a) 24 hours, b) 48 hours and c) 72 hours for the North Indian Ocean tropical cyclones for the period 1976 to 1996.

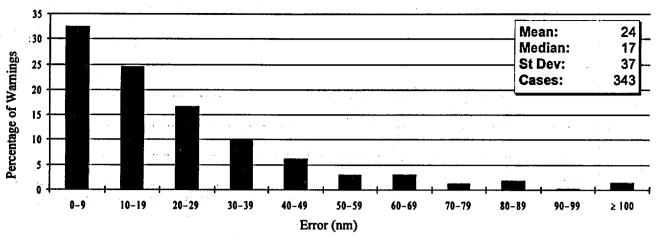


Figure 5-6a Frequency distribution of initial warning position errors (10-nm increments) for South Pacific and South Indian Ocean tropical cyclones in 1996. The largest error, 583 nm, occurred on Tropical Cyclone 20P (Zaka).

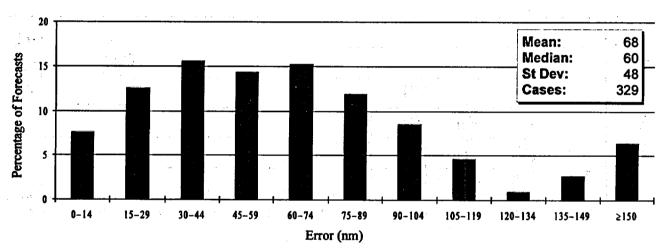


Figure 5-6b Frequency distribution of 12-hour track forecast errors (15-nm increments) for South Pacific and South Indian Ocean tropical cyclones in 1996. The largest error, 315 nm, occurred on Tropical Cyclone 24S (Hansella).

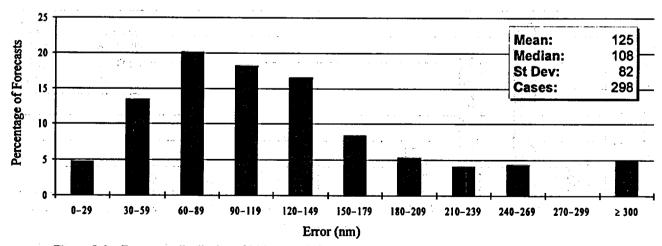


Figure 5-6c Frequency distribution of 24-hour track forecast errors (30-nm increments) for South Pacific and South Indian Ocean tropical cyclones in 1996. The largest error, 501 nm, occurred on Tropical Cyclone 27S.

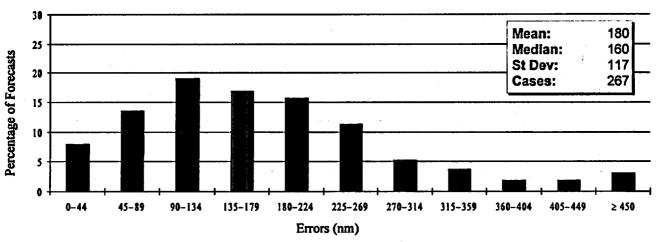


Figure 5-6d Frequency distribution of 36-hour track forecast errors (45-nm increments) for in the South Pacific and South Indian Ocean tropical cyclones in 1996. The largest error, 879 nm, occurred on Tropical Cyclone 21P (Atu).

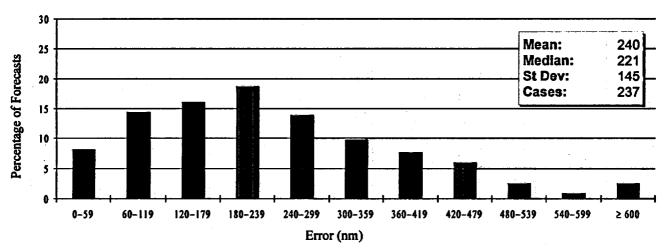


Figure 5-6e Frequency distribution of 48-hour track forecast errors (60-nm increments) for in the South Pacific and South Indian Ocean tropical cyclones in 1996. The largest error, 902 nm, occurred on Tropical Cyclone 28S (Jenna).

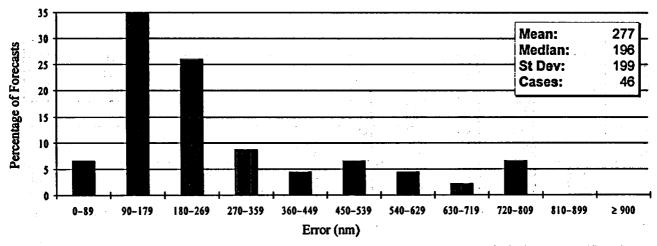


Figure 5-6f Frequency distribution of 72-hour track forecast errors (120-nm increments) for in the South Pacific and South Indian Ocean tropical cyclones in 1996. The largest error, 792 nm, occurred on Tropical Cyclone 04S (Gertie).

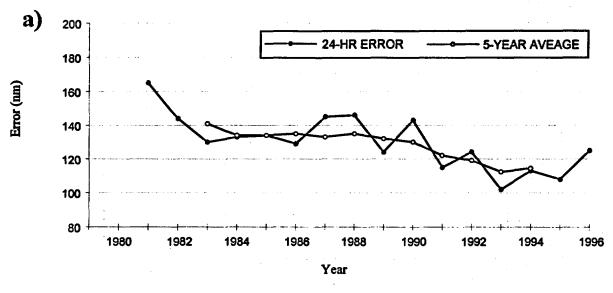
				24-HOU	R			48-HO	UR			72-HO	JR	
YEAR	number of warnings	INITIAL POSITION	NUMBER OF FORECASTS	TRACK	ALONG	CROSS	NUMBER OF FORECASTS	TRACK	ALONG	CROSS	NUMBER OF FORECASTS	TRACK	ALONG	CROS
1981	226	48	190	165	103	106	140	315	204	201				
1982	275	38	238	144	98	86	176	274	188	164				
1983*	191	35	163	130	88	77	126	241	158	145				
1984	301	36	252	133	90	79	191	231	159	134				
1985*	306	36	257	134	92	79	193	236	169	132				
1986*	279	40	227	129	86	77	171	262	169	164				
1987*	189	46	138	145	94	90	101	280	153	138				
1988*	204	34	99	146	98	83	48	290	246	144				
1989*	287	31	242	124	84	73	186	240	166	136				
1990*	272	27	228	143	105	74	177	263	178	152				
1991*	264	24	231	115	75	69	185	220	152	129				
1992*	267	28	230	124	91	64	208	240	177	129	<u> </u>		•	
1993*	257	21	225	102	74	57	176	199	142	114	ĺ			
1994*	386	28	345	115	77	68	282	224	147	134	ĺ			
1995**	245	24	222	108	82	55	175	198	144	108	53	291	169	1
1996	343	24	298	125	90	67	237	240	174	129	- 46	277	221	1
-YEAR	AVERAGE													
81-1995	263	33	219	130	89	76	169	248	170	142	53	291	169	1

^{*} These statistics are for JTWC forecasts only. NPMOC statistics are not included.

Cross-track and along-track errors were adopted by the JTWC in 1986. Right-angle (used prior to 1986) were recomputed as cross-track and along-track after-the-fact to extend the data base.

See Figure 5-1 for the definitions of cross-track and along-track errors.

^{**} JTWC began publishing 72-hour forecast verification in 1995.



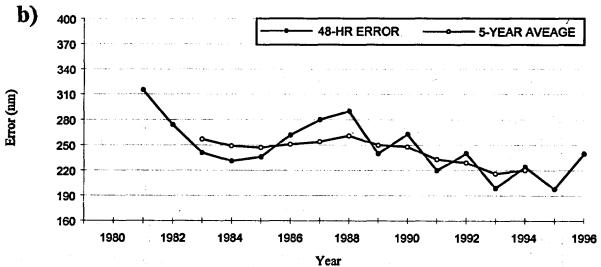


Figure 5-7 Mean track forecast error (nm) and 5-year running mean for a) 24 hours and b) 48 hours for the South Indian Ocean tropical cyclones for the period 1981 to 1996.

5.2 COMPARISON OF OBJECTIVE TECHNIQUES

JTWC uses a variety of objective techniques for guidance in the warning preparation process. Multiple techniques are required, because each technique has particular strengths and weaknesses which vary by basin, numerical model initialization, time of year, synoptic situation and forecast period. The accuracy of objective aid forecasts depends on both the specified position and the past motion of the tropical cyclone as determined by the working best track. JTWC initializes its objective techniques using an extrapolated working best track position so that the output of the techniques will start at the valid time of the next warning initial position.

Unless stated otherwise, all of the objective techniques discussed below run in all basins covered by JTWC's AOR and provide forecast positions at 12-, 24-, 36-, 48-, and 72-hours unless the technique aborts prematurely during computations. The techniques can be divided into six general categories: extrapolation, climatology and analogs, statistical, dynamic, hybrids, and empirical or analytical.

5.2.1 EXTRAPOLATION (XTRP) — Past speed and direction are computed using the rhumb line distance between the current and 12-hour old positions of the tropical cyclone. Extrapolation from the current warning position is used to compute forecast positions.

5.2.2 CLIMATOLOGY and ANALOGS

5.2.2.1 CLIMATOLOGY (CLIM) — Employs time and location windows relative to the current position of the tropical cyclone to determine which historical storms will be used to compute the forecast. The historical data base is 1945-1981 for the Northwest Pacific, and 1900 to 1990 for the rest of JTWC's AOR. Objective intensity forecasts are available from these data bases. Scatter diagrams of expected

tropical cyclone motion at bifurcation points are also available from these data bases.

5.2.2.2 ANALOG — A revised Typhoon Analog 1993 (TYAN93) picks the top matches with the basin climatology of historical tropical cyclone best tracks. Matches are based upon the differences between the direction and speed of the superimposed historical best track positions and the past direction and speed of the cyclone. Specifically, the directions and speeds are calculated from the 12-hour old position to the current "fix" position and the 24-hr old position to the "fix" position. Separate comparisons are made for climatology cyclone tracks classified as "straight," "recurver" and "other". There is also a "total" group, that includes the top matches without regard to classification of tracks.

TYAN93 works in the same manner for all basins. The time-window is +/- 35 days from the "fix." The space-window is +/- 2.5 degrees latitude and +/- 5 degrees longitude from the "fix" position on the first pass of each forecast. The maximum-wind-speed window is as follows (for basins with climatology wind speeds): a. If "fix" wind speed is ≤ 25 kt, climatology cyclone wind speed must be ≤ 30 kt. b. If "fix" wind speed is 30 kt, climatology cyclone wind speed must be in range from 25 to 35 kt. c. If "fix" wind speed is ≥ 35 kt, climatology cyclone wind speed must be at least 35 kt. Matching is based upon weighted direction and speed errors. Forecasting is based upon "straight" and "recurver" type climatology tropical cyclones, where the 12-hour and 24-hour best "straight" ("recurver") matches are combined into one set of best matches for "straight" ("recurver").

5.2.3 STATISTICAL

5.2.3.1 CLIMATOLOGY AND PERSISTENCE (CLIPER or CLIP) — A statistical regression technique that is based on climatology, current position and 12-hour and 24-hour past move-

ment. This technique is used as a crude baseline against which to measure the forecast skill of other, more sophisticated techniques. CLIP in the western North Pacific uses third-order regression equations, and is based on the work of Xu and Neumann (1985). CLIPER has been available outside this basin since mid-1990, with regression coefficients recently recomputed by FNMOC based on the updated 1900-1989 data base.

5.2.3.2 COLORADO STATE UNIVERSITY MODEL (CSUM) — A statistical-dynamical technique based on the work of Matsumoto (1984). Predictor parameters include the current and 24-hr old position of the storm, heights from the current and 24-hr old NOGAPS 500mb analyses, and heights from the 24-hr and 48hr NOGAPS 500-mb prognoses. Height values from 200-mb fields are substituted for storms that have an intensity exceeding 90 kt and are located north of the subtropical ridge. Three distinct sets of regression equations are used depending on whether the storm's direction of motion falls into "below," "on" or "above" the subtropical ridge categories. During the development of the regression equation coefficients for CSUM, the so-called "perfect prog" approach was used, in which verifying analyses were substituted for the numerical prognoses that are used when CSUM is run operationally. Thus, CSUM was not "tuned" to any particular version of NOGAPS, and in fact, the performance of CSUM should presumably improve as new versions of NOGAPS improve. CSUM runs only in the western North Pacific, South China Sea, and North Indian Ocean basins.

5.2.3.3 JTWC92 or JT92 - JTWC92 is a statistical-dynamical model for the western North Pacific Ocean basin which forecasts tropical cyclone positions at 12-hour intervals to 72 hours. The model uses the deep-layer mean height field derived from the NOGAPS forecast fields. These deep-layer mean height fields are

spectrally truncated to wave numbers 0 through 18 prior to use in JTWC92. Separate forecasts are made for each position. That is, the forecast 24-hour position is not a 12-hour forecast from the forecasted 12-hour position.

JTWC92 uses five internal sub-models which are blended and iterated to produce the final forecasts. The first sub-model is a statistical blend of climatology and persistence, known as CLIPER. The second sub-model is an analysis mode predictor, which only uses the "analysis" field. The third sub-model is the forecast mode predictor, which uses only the forecast fields. The fourth sub-model is a combination of 1 and 2 to produce a "first guess" of the 12hourly forecast positions. The fifth sub-model uses the output of the "first guess" combined with 1, 2, and 3 to produce the forecasts. The iteration is accomplished by using the output of sub-model 5 as though it were the output from sub-model 4. The optimum number of iterations has been determined to be three.

When JTWC92 is used in the operational mode, all the NOGAPS fields are forecast fields. The 00Z and 12Z tropical forecasts are based upon the previous 12-hour old synoptic time NOGAPS forecasts. The 06Z and 18Z tropical forecasts are based on the previous 00Z and 12Z NOGAPS forecasts, respectively. Therefore, operationally, the second sub-model uses forecast fields and not analysis fields.

5.2.4 DYNAMIC

5.2.4.1 NOGAPS VORTEX TRACKING ROUTINE (NGPS/X) —Tropical cyclone vortices are tracked at FNMOC by converting the 1000-mb u and v wind component fields into isogons. The intersection of isogons are either the center of a cyclonic or anticyclonic circulation, or a col. The tracking program starts at the last known location of the cyclone – a warning position. Based on this position and the last known speed and direction of movement, the program hunts for the next cyclonic

center representing the tropical cyclone. Confidence factors are generated within the program and are modified, as required, by a quality control program that formats the data for transmission.

5.2.4.2 GEOPHYSICAL FLUID DYNAMICS - NAVY (GFDN) — This model uses a triple nested movable mesh with 18 sigma levels. The outer mesh domain covers a 75°x75° area with a horizontal resolution of 1° and is fixed for the duration of the model run based on the initial location and movement of the tropical cyclone (TC). The 10°x10° middle and a 5°x5° inner (resolution 1/6°) nested meshes move with the cyclone. Based on the global analysis and an initialization message, the TC is removed from the global analysis, and replaced by a synthetic vortex which has an asymmetric (beta-advection) component added. Boundary conditions are updated periodically from forecast fields generated by a global forecast model. In addition to standard output fields, the model outputs TC track forecasts and maximum isotach swaths indicating the location of maximum winds in relation to the TC track.

5.2.4.3 ONE-WAY (INTERACTIVE) TROPI-CAL CYCLONE MODEL (OTCM) — This technique is a coarse resolution (205-km grid), three layer, primitive equation model with a horizontal domain of 6400 x 4700 km. OTCM is initialized using 6-hour or 12-hour prognostic fields from the latest NOGAPS run, and the initial fields are smoothed and adjusted in the vicinity of the storm to induce a persistence bias into OTCM's forecast. A symmetric bogus vortex is then inserted, and the boundaries updated every 12 hours by NOGAPS fields as the integration proceeds. The bogus vortex is maintained against frictional dissipation by an analytical heating function. The forecast positions are based on the movement of the vortex in the lowest layer of the model (effectively 850-mb).

5.2.4.4 FNMOC BETA AND ADVECTION MODEL (FBAM) — This model is an adaptation of the Beta and Advection model used by NCEP. The forecast motion results from a calculation of environmental steering and an empirical correction for the observed vector difference between that steering and the 12-hour old storm motion. The steering is computed from the NOGAPS Deep Layer Mean (DLM) wind fields which are a weighted average of the wind fields computed for the 1000-mb to 100mb levels. The difference between past storm motion and the DLM steering is treated as if the storm were a Rossby wave with an "effective radius" propagating in response to the horizontal gradient of the coriolis parameter, beta. The forecast proceeds in one-hour steps, recomputing the effective radius as beta changes with storm latitude, and blending in a persistence bias for the first 12 hours.

5.2.5 HYBRIDS

- 5.2.5.1 HALF PERSISTENCE AND CLIM-ATOLOGY (HPAC) Forecast positions generated by equally weighting the forecasts given by XTRP and CLIM.
- 5.2.5.2 BLENDED (BLND) A simple average of six forecast aids: OTCM, CSUM, FBAM, JT92, CLIP, and HPAC.
- 5.2.5.3 WEIGHTED (WGTD) A weighted average of the forecast guidance used to compute BLND: OTCM (29%), CSUM (22%), FBAM (14%), JT92 (14%), HPAC (14%), and CLIP (7%).
- 5.2.5.4 DYNAMIC AVERAGE (DAVE) A simple average of all dynamic forecast aids: NOGAPS (NGPS), Bracknell (EGRR), Japanese Typhoon Model (JTYM), JT92, FBAM, OTCM, and CSUM.

5.2.6 EMPIRICAL OR ANALYTICAL

5.2.6.1 DVORAK — An estimation of a tropical cyclone's current and 24-hour forecast intensity is made from the interpretation of satellite imagery (Dvorak, 1984). These intensity estimates are used with other intensity related data and trends to forecast short-term tropical cyclone intensity.

5.2.6.2 MARTIN/HOLLAND — The technique adapts an earlier work (Holland, 1980) and specifically addresses the need for realistic 35-, 50- and 100-kt (18-, 26- and 51-m/sec) wind radii around tropical cyclones. It solves equations for basic gradient wind relations within the tropical cyclone area, using input parameters obtained from enhanced infrared satellite imagery. The diagnosis also includes an asymmetric area of winds caused by tropical cyclone movement. Satellite-derived size and intensity parameters are also used to diagnose internal steering components of tropical cyclone motion known collectively as "beta-drift."

5.2.6.3 TYPHOON ACCELERATION PRE-DICTION TECHNIQUE (TAPT) — This technique (Weir, 1982) utilizes upper-tropospheric and surface wind fields to estimate acceleration associated with the tropical cyclone's interaction with the mid-latitude westerlies. It includes guidelines for the duration of acceleration, upper limits and probable path of the cyclone.

5.3 TESTING AND RESULTS

A comparison of selected techniques is included in Table 5-5 for all western North Pacific tropical cyclones, Table 5-6 for all North Indian Ocean tropical cyclones and Table 5-7 for the Southern Hemisphere. For example, in Table 5-5 for the 12-hour mean forecast error, 925 cases available for a homogeneous comparison, the average forecast error at 12 hours was 73 nm (135 km) for CSUM and 69 nm (128 km) for FBAM. The difference of 4 nm (7 km) is shown in the lower right. Differences are not always exact, due to computational round-off which occurs for each of the cases available for comparison.

Table 5-5 1996 ERROR STASTISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTHWEST PACIFIC (1 JAN 1996 - 31 DEC 1996) 12-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM **GFDN** CSUM CLIP **FBAM** DAVE JTWC Number X-Axis of Technique NGPS Cases Error n OTCM Y-Axis Error Difference O Technique **GFDN** (Y-X) Error -48 FBAM ้วก -17 -57 -21 **CSUM** -53 -13 -16 Λ CLIP -14 -54 -18 DAVE -15 -52 -20 -2 -2 24-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM **GFDN FBAM CSUM** CLIP DAVE JTWC NGPS OTCM **GFDN** -83 **FBAM** -6 -75 -11 **CSUM** -63 CLIP -2 -70 DAVE -11 -20 -5 -20 -13 36-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM **GFDN** FBAM CSUM CLIP DAVE JTWC NGPS OTCM n **GFDN** -11 -94 **FBAM** -75 O **CSUM** -59 CLIP -68 -6 DAVE -9 -93 -18 -18 -40 -31

Table 5-5 (CONTINUED) 1996 ERROR STASTISTICS FOR SELECTED OBJECTIVE TECHNIQUES

IN THE NORTHWEST PACIFIC

(1 JAN 1996 - 31 DEC 1996)

48-HOUR MEAN FORECAST ERROR (NM)

	Jī	rwc	NO	SPS	OT	CM	GE	DN	F	BAM	CS	MUS	C	LIP	DA	AVE
JTWC	711	178														
	178	0														
NGPS	460	160	512	179												
	177	17	179	0												
OTCM	500	165	379	169	586°	290										
	291	126	293	124	290	0										
GFDN	386	160	305	183	306	301	406	191								
	188	28	191	8	186		191	0								
FBAM	672	178	473	179	546	290	387	194	868	218						
	209	31	206	27	208	-82	211	17	218	0						
CSUM	660	178	452	180	524	291	377	193	820	218	831	253	•			
	247	69	247	67	235	-56	248	55	253	35	253	0				
CLIP	692	177	483	179	550	292	396	191	849	217	817	253	884	247		
	238	61	228	49	230	-62	236	45	248	31	249	-4	247	0		
DAVE	548	181	387	186	437	294	300	201	650	222	631	253	658	246	672	192
	184	3	172	-14	183		179	-22	192	-30	192	-61	192	-54	192	0
	104	,			•				ST ERR	OR (N	M)			*.		
		,			72 - I	HOUR M	1EAN F	ORECAS			-	!TTM	Cī	TD	מח	WE
JTWC		- WC 272		:PS	•	HOUR M	1EAN F			OR (NI	-	UM	CI	.IP	DA	VE
JTWC	JT	:WC			72 - I	HOUR M	1EAN F	ORECAS			-	SUM	CI	IP.	DA	VE
JTWC NGPS	JT 607 272 375	- - 			72 - I	HOUR M	1EAN F	ORECAS			-	NUM	CI	.IP	DA	VE
	JT 607 272 375 258	CWC 272 0 260 -2	NG	:PS	72 - I	HOUR M	1EAN F	ORECAS			-	BUM	CI	JP.	DA	VE
	JT 607 272 375 258 391	CWC 272 0 260	NG 418	3PS 267	72 - I	HOUR M	1EAN F	ORECAS			-	SUM	CI	ΙP	DA	VE
NGPS	JT 607 272 375 258	CWC 272 0 260 -2	NG 418 267	3PS 267 0	72-1 OT	HOUR M	1EAN F	ORECAS			-	SUM	CI	ΙP	DA	VE
NGPS	JT 607 272 375 258 391 414 198	272 0 260 -2 249 165 253	NG 418 267 280	267 0 251	72-E OT	HOUR M	1EAN F	ORECAS			-	SUM	CI	ΙP	DA	VE
ngps otcm	JT 607 272 375 258 391 414 198 268	272 0 260 -2 249 165	NG 418 267 280 413	267 0 251 162	72-F OTC 439 419	HOUR M CM 419 0 377	1EAN F	ORECAS			-	UM	CI	.IP	DA	VE
ngps otcm	JT 607 272 375 258 391 414 198	272 0 260 -2 249 165 253	NG 418 267 280 413 139	267 0 251 162 268	72-F OT 6 439 419 139	HOUR M CM 419 0 377	4EAN F GF 209	ORECAS DN 270			-	UM	CI	.TP	DA	VE
NGPS OTCM GFDN FBAM	JT 607 272 375 258 391 414 198 268 575 311	7WC 272 0 260 -2 249 165 253 15 271 40	NG 418 267 280 413 139 289	267 0 251 162 268 21	72-F OTC 439 419 139 250	HOUR M CM 419 0 377 -127 419	MEAN F GF 209 270	ORECAS ON 270 0	FE	BAM	-	UM	CI	,TP	DA	\VE
NGPS OTCM GFDN	JT 607 272 375 258 391 414 198 268 575 311 568	272 0 260 -2 249 165 253 15 271 40 273	NG 418 267 280 413 139 289 392	267 0 251 162 268 21 265	72-F OTC 439 419 139 250 413	HOUR M CM 419 0 377 -127 419	1EAN F GF 209 270 198	ORECAS ON 270 0 278	752	324	-	382	CI	.IP	DA	\VE
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81 NGPS 89 8 87 OTCM 90 7 104 3 FBAM 126 7 86 CLIM 124 7 99 2 CLIF 131 8 83 HPAC 131 8 88 WGTD 105 7 91 1 JTWC JTWC 123 13 134 NGPS 84 13 135 OTCM 82 12 187 6 FBAM 118 13 148 1 CLIM 116 13 166 3 CLIP 123 13 139 HPAC 123 13 139 HPAC 123 13 139 HPAC 123 13 148 1 WGTD 98 13 154 2 JTWC JTWC JTWC JTWC JTWC JTWC JTWC JT			4.0												
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Table 5-6 (CONTINUED) 1996 ERROR STASTISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTH INDIAN OCEAN (1 JAN 1996 - 31 DEC 1996) 48-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM **FBAM** CLIM CLIP **HPAC** WGTD JTWC NGPS -26 OTCM **FBAM** Ω CLIM -51 -50 CLIP -78 -73 -22 **HPAC** -68 -9 -60 WGTD -25 72-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS **FBAM** OTCM CLIM CLIP **HPAC** WGTD JTWC n NGPS -17 OTCM **FBAM** -94 CLIM -31 -77 330 -141 CLIP -32 312 -114 317 -133 **HPAC** -14 -88 336 -114 WGTD 288 -175 -79

36-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM FBAM CLIM CLIP HPAC WGTM JTWC 180 0 NGPS 210 173 331 197 185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0				714	THE :	3001112	ita iidi	MI OF HE	KE (I	005,1	.993 -	30 00	M 199	0,			
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103 38 106	ICD6			300	106												
CTCM 309	IGES													•			
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FBAM 275 124 337 149 474 124 487 131 129 5 128 -21 128 4 131 0 CLIM 277 124 338 149 477 124 487 131 490 166 163 39 153 4 162 38 166 35 166 0 CLIP 285 126 337 149 482 126 486 131 489 166 498 151 151 25 136 -13 147 21 151 20 151 -15 151 0 HPAC 286 126 338 149 483 127 487 131 490 166 498 151 4 145 19 131 -18 140 13 143 12 143 -23 144 -7 144 0 MGTD 188 123 238 154 322 125 327 129 329 163 329 142 329 139 329 121 -2 116 -38 120 -5 122 -7 122 -41 122 -20 122 -17 122 36-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM FBAM CLIM CLIP HPAC WGT! JTWC 267 180 180 0 NGPS 210 173 331 197 185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0	TCM																•
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CLIM 277 124 338 149 477 124 487 131 490 166 163 39 153 4 162 38 166 35 166 0 CLIP 285 126 337 149 482 126 486 131 489 166 498 151 151 25 136 -13 147 21 151 20 151 -15 151 0 HPAC 286 126 338 149 483 127 487 131 490 166 498 151 499 144 145 19 131 -18 140 13 143 12 143 -23 144 -7 144 0 WGTD 188 123 238 154 322 125 327 129 329 163 329 142 329 139 329 121 -2 116 -38 120 -5 122 -7 122 -41 122 -20 122 -17 122 36-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM FBAM CLIM CLIP HPAC WGTM 180 0 NGPS 210 173 331 197 185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0	DAM																
163 39 153 4 162 38 166 35 166 0 CLIP 285 126 337 149 482 126 486 131 489 166 498 151 151 25 136 -13 147 21 151 20 151 -15 151 0 HPAC 286 126 338 149 483 127 487 131 490 166 498 151 499 144 145 19 131 -18 140 13 143 12 143 -23 144 -7 144 0 NGTD 188 123 238 154 322 125 327 129 329 163 329 142 329 139 329 121 -2 116 -38 120 -5 122 -7 122 -41 122 -20 122 -17 122 36-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM FBAM CLIM CLIP HPAC WGTM 180 0 NGPS 210 173 331 197 185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 451 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0	LIM		-				_		-	490	166					. *	
151 25																	
HPAC 286 126 338 149 483 127 487 131 490 166 498 151 499 144 145 19 131 -18 140 13 143 12 143 -23 144 -7 144 0 WGTD 188 123 238 154 322 125 327 129 329 163 329 142 329 139 329 121 -2 116 -38 120 -5 122 -7 122 -41 122 -20 122 -17 122 36-HOUR MEAN FORECAST ERROR (NM) JTWC	LIP	285	126	337	149	482	126	486	131	489	166	498	151				
MGTD 188 123 238 154 322 125 327 129 329 163 329 142 329 139 329 121 -2 116 -38 120 -5 122 -7 122 -41 122 -20 122 -17 122 36-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM FBAM CLIM CLIP HPAC WGTM 180 0 NGPS 210 173 331 197 185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0										151	-15	151	0				
WGTD 188 123 238 154 322 125 327 129 329 163 329 142 329 139 329 121 -2 116 -38 120 -5 122 -7 122 -41 122 -20 122 -17 122 36-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM FBAM CLIM CLIP HPAC WGTM 180 0 180 0 NGPS 210 173 331 197 185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0	IPAC															1.5	· ·
36-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM FBAM CLIM CLIP HPAC WGTI JTWC 267 180 180 0 NGPS 210 173 331 197 185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0	CMD														-		
36-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM FBAM CLIM CLIP HPAC WGTM JTWC 267 180 180 0 NGPS 210 173 331 197 185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0	GTD				_												122
JTWC NGPS OTCM FBAM CLIM CLIP HPAC WGTM JTWC 267 180 180 0 NGPS 210 173 331 197 185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0			-2	110	-36								-20	122	-17	122	. 0
JTWC 267 180 180 0 NGPS 210 173 331 197 185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0						36-	HOUR	MEAN F	ORECA	ST ERR	OR (N	M)	•			. •	
180 0 NGPS 210 173 331 197 185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0				NG	PS	OI	CM	F	BAM	CI	MI	CI	IP	HP	AC	WG	TD
NGPS 210 173 331 197 185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0	TWC														•	•	
185 12 197 0 OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0	CPG			321	107											•	
OTCM 246 177 302 196 442 181 177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0																	•
177 0 180 -16 181 0 FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0						442	181										
FBAM 248 178 308 196 435 178 453 194 192 14 194 -2 188 10 194 0 CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0																	
CLIM 250 177 309 196 434 177 449 194 452 230 227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0	BAM							453	194				,		•		
227 50 220 24 229 52 230 36 230 0 CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0									0								
CLIP 257 181 308 196 437 180 448 194 451 230 459 207 209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0	LIM																
209 28 195 -1 203 23 206 12 206 -24 207 0 HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0																	
HPAC 258 181 309 196 438 180 449 194 452 230 459 207 460 202 204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0	LIP																
204 23 190 -6 199 19 201 7 201 -29 202 -5 202 0	ממי													460	202		* .
	rac																
	GTD	172	23 177	219	206	296	180	307	194	306	230	306	-5 200	306	198	309	175
																	1/3

Table 5-7 (CONTINUED) 1996 ERROR STASTISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE SOUTHERN HEMISPHERE (1 JUL 1995 - 30 JUN 1996) 48-HOUR MEAN FORECAST ERROR (NM) JTWC NGPS OTCM **FBAM** CLIM CLIP HPAC WGTD JTWC NGPS -1 OTCM FBAM CLIM CLIP -30 **HPAC** -34 -4 WGTD -20 -20 -27 -28 -68 -29 Λ

. •	JT	MC .	· NO	PS	07	CM	F	BAM	CI	IM	CI	LIP	H	PAC	Wo	GTD
JTWC	46	277														
	277	0														
NGPS	41	267	218	353												
	238	-29	353	0												
OTCM	35	246	182	352	308	367										
	413	167	389	37	367	0					•					
FBAM	44	275	205	360	303	362	348	370								
	384	109	384	24	355	-7	370	0								
CLIM	44	275	206	360	306	361	348	370	351	414				•		
	452	177	416	56	405	44	414	44	414	0					•	
CLIP	44	275	205	359	306	362	347	370	350	413	354	394				
	375	100	362	3	367	5	396	26	396	-17	394	0	•			
HPAC	44	275	206	360	308	367	348	370	351	414	354	394	356	380		
	358	83	348	-12	358	÷9	378	- 8	378	-36	376	-18	380	. 0		
WGTD	11	216	14	343	13	439	14	489	14	467	14	281	14	204	14	409
	474	258	409	66	404	-35	409	-80	409	-58	409	128	409	205	409	0

6. TROPICAL CYCLONE WARNING VERIFICATION STATISTICS

6.1 GENERAL

Since 1959, JTWC has compiled data on tropical cyclones (TC) within its AOR. In this 38-year period, over 32,000 warnings were verified on 1,800 TCs. The verification data include best tracks (6-hourly positions and associated intensities), JTWC forecasts (12-, 24-, 36-, 48- and 72-hour position, intensity and wind radii), and fixes made from satellite, aircraft, radar, and synoptic data. These data are archived and available upon request.

Efforts are underway to make this information available via anonymous FTP over the Internet, however, until this project is complete JTWC will provide the data by FTP

upon request. To request data by Internet, send e-mail to: jtops@npmocw.navy.mil. If the Internet is not an option, data can be copied to 3.5" computer diskettes (that you provide) upon request. Plan for one diskette for each year and ocean basin. Mail them with your request to: NAVPACMETOCCEN WEST /JTWC, PSC 455, Box 12, FPO AP 96540-0051.

6.2 WARNING VERIFICATION STATISTICS

6.2.1 WESTERN NORTH PACIFIC — This section includes verification statistics for each significant TC in the western North Pacific during 1996.

JTWC BEST TRACK, FORECAST TRACK AND INTENSITY ERRORS BY WARNING

TROPICAL DEPRESSION 01W

	WRN	В	EST TRA	CK		POS	ITION	ERR	ORS -			W	IND	ERRO	RS	
DTG	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72
				(KT)												
96022306		4.0N	148.7E	20												
96022312		4.0N	148.6E	20												
96022318		4.1N	148.6E	20												
96022400		4.1N	148.5E	20												
96022406		4.2N	148.4E	20												
96022412		4.2N	148.3E	25												
9602241B		4.3N	148.2E	25												
96022500		4.3N	148.1E	25												
96022506		4.3N	148.0E	25												
96022512		4.3N	147.5E	25												
96022518		4.8N	146.8E	25												
96022600		5.2N	145.7E	25												
96022606		5.7N	144.4E	25												
96022612		6.1N	143.0E	25												
96022618		6.7N	141.3E	25												
96022700		7.3N	139.5E	25												
96022706		8.0N	137.7E	25												
96022712		B.4N	136.1E	20												
96022718		B.7N	134.5E	20												
96022800		8.9N	133.0E	20												
96022806		9.0N	131.5E	20												
96022812		9.1N	130.0E	25												
96022818		9.3N	128.7E	25												
96022900		9.5N	127.4E	25												
				-												

TROPICAL	DEPR	ESSION	01W (CONTIN	UED)								
96022906	1	9.9N	126.3	E 30	21	68	127	129		0	5	15	20
96022912	2	10.1N	125.3	€ 30	29	90	112	100		0	5	10	20
96022918	3	10.5N	124.1	E 30	21	82	98			0	0	0	
96030100	4	10.7N	122.7	E 30	18	60	83			0	0	10	
96030106	5	10.6N	121.4	E 30	50	82				0	0		
96030112	6	10.6N	120.4	E 30	25	50				0	5		
96030118	7	10.6N	119.6	E 30	29					0			
96030200		10.6N	118.8	E 25									
			AVER	AGE	28	72.	106	115					
			# CAS	SES	7	6	4	2					
TROPICAL	STOR	M ANN	(02W)										
	WRN	В	EST TR	ACK		PC	SITIC	N ERRORS	3		W	IND	ERRO

	WRN		EST TRA	~~		D.C		N ERP	OBC				JTNR	EDDO	n c	
DTG	NO.		LONG		00					70	0.0			ERRO		72
DIG	NO.	LAT	LUNG	WIND	00	12	24	36	48	72	00	12	24	36	48	72
0.0000000		4 011	150 15	(KT)	·											
96032918			150.1E	15												
96033000			150.0E	20												
96033006			149.9E	20												
96033012			149.8E	20												
96033018			149.6E	25												
96033100			149.2E	25												
96033106			148.6E	25												
96033112			147.6E	25												
96033118			146.6E	25												
96040100			145.7E	25												
96040106			145.1E	25												
96040112			144.5E	30												
96040118			143.8E	30												
96040200	1		143.0E	35	166	268	373	450	546	854	-10	-5	0	5	10	20
96040206	2		142.1E	35	212	269	340	401	445	534	-5	-5	0	5	15	15
96040212	3		141.5E	35	215	275	321	347	374	433	-5	-5	0	10	15	10
96040218	4		140.8E	35	222	257	300	331	366	446	-5	0	0	15	15	10
96040300	5		139.9E	35	196	186	178	235	275	366	0	0	10	20	30	30
96040306	6		139.3E	35	186	189	208	269	310	413	0	0	15	20	25	30
96040312	7		138.5E	35	183	162	173	193	215	302	0	5	15	15	15	20
96040318	8		137.8E	35	198	212	233	254	293	353	0	10	15	10	15	10
96040400	9		137.2E	30	206	278	359	441			0	0	0	-10		
96040406			136.3E	25												
96040412	10		135.5E	25	201	223	237				0	0	-10			
96040418			134.7E	25												
96040500	11	9.6N	133.8E	25	142	152	172	177			0	-10	-10	-10		
96040506			133.0E	30												
96040512	12	9.5N	132.1E	35	115	128	136	127	138	163	0	5	10	10	15	30
96040518	13		130.9E	35	123	128	119	84	91	149	0	5	5	10	20	30
96040600	14	9.6N	129.7E	35	79	70	69	105	170	312	0	5	5	5	15	30
96040606	15	9.7N	128.7E	35	72	58	82	147	232	399	0	0	-5	5	15	25
96040612	16	9.9N	127.7E	35	94	105	102	159	234	378	0	-5	-5	0	10	15
96040618	17	10.2N	126.7E	40	104	131	194	294	399	644	0	-5	0	10	10	25
96040700	18	10.7N	125.7E	40	63	76	152	236	322	490	0	0	5	10	15	25
96040706	19	11.3N	125.0E	40	13	29	79	129	185	316	0	5	10	10	20	25
96040712	20	11.7N	124.3E	40	0	39	79	105	172	299	0	5	10	10	20	30
96040718	21	11.9N	123.8E	35	31	76	132	197	255	318	0	5	0	10	20	30
96040800	22	12.2N	123.4E	35	29	72	137	202	274	364	0	5	0	10	20	30
96040806	23	12.4N	123.1E	30	34	59	117	172	222	304	0	0	0	5	10	20
96040812	24	12.6N	122.8E	30	50	105	166	226	273	355	0	0	0	5	15	20
96040818	25	12.4N	122.5E	30	16	11	26	50	76	142	0	5	5	5	15	20
96040900	26	12.1N	122.3E	30	26	48	68	78			0	5	5	10		
96040906		11.8N	122.1E	25												
96040912	27	11.6N	121.9E	25	108	142	123				0	5	10			
96040918		11.4N	121.7E	20												
96041000		11.3N	121.5E	20												
96041006		11.3N	121.3E	20												
96041012		11.3N	121.1E	15												
96041018		11.4N	120.9E	15												
96041100		11.5N	120.7E	15												
96041106		11.7N	120.5E	15												
96041112		11.9N	120.3E	15												
96041118			120.1E	15												

AVERAGE # CASES 115 139 174 217 267 379 27 27 27 25 22 22

TROPICAL DEPRESSION 03W

	WRN		EST TRA	CK		90	SITIC	W EDI	O T O				TMD	ERR	ADC		
200																20	
ÐTG	NO.	LAT	LONG	WIND	. 00	12	24	36	48	72	00	12	24	36	48	72	
				(KT)													
96042500		7.7N	113.6E	20													
96042506			113.1E														
96042512					22	26					•						
	1		112.6E		23	35					0	5					
96042518	2	7.1N	112.0E	25	24	24					0	5					
96042600	3	7.2N	111.4E	25	0						0						
96042606	4	7.3N	110.9E	20	0						0						
30042000	•	,.514	110.75	20	•						۰						
			AVERA	GE	12	30											
			# CAS	ES	4	2											
TYPHOON I	0300	46 4371															
TIPHOON	DARI	(0411)															
	WRN	B	EST TRA	CK		PC	SITIC	N ERF	RORS			1	NIND	ERR	DRS		
DTG	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24		48	72	
		2	201.0		•••				70		00			70			
				(KT)													
96050700			137.8E	15													
96050706		6.BN	138.0E	15													
96050712		6.9N	138.4E	15													
96050718			138.9E	15													
96050800			139.2E	15													
96050806		7.1N	139.4E	15													
96050812		7.1N	139.7E	20													
96050818			139.9E	20													
96050900	_		139.9E	20									_	_	_	7.2	
96050906	1		139.7E	25	13	12	56	122	159	169	0	0	0	-5	-5	-5	
96050912	2	7.8N	139.3E	25	11	53	136	218	218	150	0	0	5	10	10	10	
96050918	3	8.1N	138.7E	30	21	84	172	239	215	163	0	0	0	5	10	10	
	4										-						
96051000			138.0E	35	37	127	223	240	256	252	0	0	0	0	5	. 5	
96051006	5	9.0N	136.9E	35	42	111	162	138	131	133	0	-5	-5	0	5	-5	
96051012	6	9.6N	135.9E	40	45	115	106	114	125	133	-5	-5	-10	-10	-10	-35	
96051018	7	10.5N	134.7E	45	60	67	35	65	140	330	0	0	5	10		-40	
96051100	8		133.6E	45	66	26	31	30	96	222	0	-5	0	5		-55	
96051106	9	11.7N	132.5E	50	41	32	47	23	24	72	-5	-5	0	5	-5	-35	
96051112	10	11.7N	131.7E	55	18	50	44	17	21	62	0	0	5	5	-5	-20	
96051118	11		130.8E	55	8	17	21	44	58	45	ō	ō	5		-20		
					_												
96051200	12		129.7E	60	26	43	42	68	111	196	0	0	0	_	-25		
96051206	13	12.6N	128.9E	60	5	24	13	36	77	154	0	0	-10	-20	-25	-20	
96051212	14	13.2N	128.3E	65	8	23	55	91	147	217	0	-5	-20	-35	-20	-20	
96051218	15	13.6N	127.9E	65	17	45	96	145	211	244	Ó			-35			
96051300	16			75		39					-						
			127.5E		5		65	91	130	168		-25					
96051306	17	14.5N	127.0E	85	5	34	40	64	68	92	-10	-30	-35	-15	-10	-20	
96051312	18	15.0N	126.5E	95	13	30	55	78	90	176	-5	-25	-10	~5	-15	-15	
96051318	19	15.4N	126.1E	110	6	26	34	45	62	152	-10	-15	0	5	0	5	
96051400	20			125	5	24	42	32	35	154	0	15	20	5	-5	10	
96051406	21		125.5E		6	34	37	36	22	124	0	10	10	0	-5	10	
96051412	22	16.6N	125.2E	120	8	21	57	74	98	71	-5	-15	-25	-40	-40	-20	
96051418	23	17.2N	124.9E	115	0	18	34	62	74	199	0	-15	-25	-40	-30	-10	
96051500	24		124.8E		ō	11	34	49	84	247	Ö	.0			-10	Õ	
96051506	25															-	
			124.8E		. 0	34	75	141	181	307	0			-15		-5	
96051512	26		125.0E		11	17	23	67	168	414	0	0	-5	5	0	10	
96051518	27	19.1N	125.4E	115	8	45	129	237	363	576	0	0	5	10	10	5	
96051600	28		125.9E		5	39	121	228	303	385	0	10	15	10	15	Ö	
96051606	29		126.6E		6	34	102	190	245	340	ŏ	20	20	20	20	Ö	
96051612	30		127.5E		12	78	204	289	320	491	-5	0		-10		-10	
96051618	31	20.4N	128.8E	95	21	78	156	222	240		-5	-10	-20	-10	-10		
96051700	32	21.1N	130.2E	85	0	60	113	139	174			-15		-5			
96051706	33		131.7E	80	24	82	121	141	255		-10	-5	-5	-5			
96051712	34		133.3E	75	6	8	48	101	303		-10	-5		-10	-10		
96051718	35	24.6N	135.1E	65	36	128	192	240			0	0	-5	-10			
96051800	36		136.8E	55	12	34	92	294			5	5		-10			
96051806	37		138.4E	50	40	86	194				5		-10				
											-						
96051812	38		140.3E	45	8	37	166					-10	-15				
96051818	39	28.2N	142.0E	45	0	68					-5	-10					
96051900		28.7N	144.2E	45													
96051906			147.2E	45													
96051912		30.4M	151.9E	. 45													
			AVERA	GE.	17	49	89	123	154	215							
			# CASI		39	39	38	36	34	30							
						3,	30		,,	30							

TROPICAL STORM CAM (05W)

	WRN	В	EST TRA		PC	SITIC	N ERI	RORS			WIND ERRORS						
DTG	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72	
				(KT)						•							
96051600		13.0N	110.9E	15													
96051606		13.2N	111.1E	15													
96051612		13.3N	111.3E	15													
96051618		13.4N	111.5E	15													
96051700		13.5N	111.6E	15													
96051706		13.6N	111.8E	15													
96051712			111.9E	15													
96051718			112.1E	15													
96051800			112.3E	15													
96051806			112.5E	20													
96051812			112.7E	20				-									
96051818	1		112.9E	25	48	84	141	159	162	256	0	5	5	5	5	-5	
96051900	2		113.3E	25	66	129	156	179	188	257	0	5	5	5	0	0	
96051906	3		113.9E	25	56	103	128	141	165	240	0	0	0	0	-5	0	
96051912	4		114.5E	25	67	96	117	126	164	243	0	0	0	-5	-5	0	
96051918	- 5		115.0E	30	74	93	95	130	174	280	0	0	0	-5	0	5	
96052000	6		115.4E	30	13	37	25	18	24	73	0	0	-5	-5	0	5	
96052006	7		115.7E	35	20	51	49	41	45	16	0	0	-5	5	10	20	
96052012	8		116.0E	35	18	48	66	79	84	152	0	0	5	10	10	5	
96052018	. 9		116.3E	40	18	49	74	100	130	283	-5	-5	0	5	-5	10	
96052100	10		116.9E	45	12	59	112		225	350				-10	-20	5	
96052106	11		117.5E	50	20	53	92	143	212		-	-10	_	-15			
96052112	12		118.2E	50	16	21	24	12	12		-	-10		-10	-5		
96052118	13		118.9E	55	12	23	26	16	42			-10			-5		
96052200	14		119.6E	55	6	13	26	29	75			-10			5		
96052206	15		120.3E	55	6	32	53	67						-5			
96052212	16		121.1E	55	12	26	41	88				-20		5			
96052218	17		122.0E	60	18	25	44				-15		-5				
96052300	18		122.9E	60	21	25	61				-15		5				
96052306	19		123.9E	55	25	28	: .				-10	5					
96052312	20		124.9E	50	30	126					-5	10					
96052318	21		126.4E	40	32						0						
96052400	22	21.9N	128.0E	30	69						. 0						
			AVERA		30	57	74	94	122	215							
			# CASI	ES	22	20	18	. 16	14	10							

TYPHOON DAN (06W)

	WRN	В	EST TRA		POSITION ERRORS						WIND ERRORS						
DTG	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72	
				(KT)													
96070312		19.0N	155.6E	15													
96070318		18.9N	154.9E	15													
96070400		18.9N	154.2E	15													
96070406		18.9N	153.4E	15			-										
96070412		18.9N	152.4E	15						*							
96070418		19.0N	151.3E	20													
96070500	1	19.1N	150.2E	25	72	90	131	174	201	213	0	5	10	5	5	0	
96070506	2	19.3N	149.2E	25	74	91	130	166	187	215	. 0	5	5	5	0	.0	
96070512	3	19.5N	148.2E	25	85	124	186	203	217	279	0	5	0	5	5	10	
96070518	4	19.8N	147.3E	25	82	92	114	120	127	239		0	0	0	-5	5	
96070600	5	20.1N	146.6E	25	8	13	21	39	37	129	0	-5	-5	-5	-15	-15	
96070606	6	20.4N	146.0E	30	8	8	12	20	50	201	. 0	-5	-5	-10	-10	-15	
96070612	7	20.6N	145.5E	35	6	12	23	39	50	195	- 5	-5	-5	-15	-10	-10	
96070618	8	20.9N	144.9E	35	17	57	79	93	64	219	0	Ó	-5	0	5	10	
96070700	9	21.2N	144.2E	40	16	43	35	60	103	332	0	-5	-10	0	0	10	
96070706	10	21.6N	143.5E	45	18	24	52	85	174	397	0	-10	-10	-5	0	15	
96070712	11	22.1N	142.7E	50	45	73	97	150	254	443	0	-5	5	5	15	20	
96070718	12	22.4N	142.0E	60	21	45	69	72	84	223	-5	Ö	5	10	20	15	
96070800	13	22.BN	141.3E	65	8	54	114	187	252	390	0	Ō	0	10	20	15	
96070806	14	23.4N	140.8E	65	16	72	125	174	176	313	0	5	-5	-5	-5	-5	
96070812	15	24.0N	140.6E	65	24	65	115	146	142	248	0	-10	-15	-10	-10	-15	
96070818	16	24.7N	140.5E	70	36	85	124	131	138	296	-5	-10	-10	-5	-10	-15	
96070900	17	25.5N	140.5E	75	13	80	167	234	315	618	0	-5	-5	-5	-10	-15	
96070906	18	26.7N	140.6E	75	24	90	155	226	336	559	0	0	0	-5	-5	-15	
96070912	19	28.0N	140.7E	75	6	42	67	113	214	266	0	0	0	-5	-5	-10	
96070918	20	29.5N	140.8E	70	8	18	53	115	213	144	. 0	-5	-10	-15	-20	-15	
96071000	21	31.0N	141.0E	70	26	36	71	99	96	130	0	-5	-15	-15	-25	-15	
96071006	22	32.4N	141.2E	65	20	94	127	161	114	157	0	-5	-10	-15	-25	-15	
96071012	23	33.7N	141.8E	65	34	120	259	320	247	253	-10	-15	-20	-25	-25	-5	
96071018	24	35.0N	142.9E	65	15	86	225	255	130	169	-15	-20	-25	-25	-20	-5	
96071100	25	36.4N	144.2E	65	24	79	124	100	99		-15	-20	-25	-20	-15		

DTG

NO.

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TYPHOON DAN (06W) (CONTINUED)
96071106 26 37.9N 145.8E 60 29 138 232 253 96071112 27 39.8N 147.9E 60 11 166 326 407 96071118 28 42.0N 149.6E 60 58 211 346 445 96071200 29 43.9N 150.8E 60 49 194 381 472 96071206 30 45.3N 151.6E 60 103 280 469 559
                                             29 138 232 253 249
                                                                                      -10 -20 -25 -15 -15
                                                                                      -20 -20 -20 -10
                                                                                      -25 -25 -15 -10
                                                                                        0 0 -5 -10
0 0 -5 -5
96071212
                   45.8N 152.3E 55
96071218
                 45.9N 153.2E 50
96071300
                   45.6N 154.7E 45
                   45.2N 157.1E 45
45.1N 159.9E 35
96071306
96071312
96071318
                   45.0N 162.1E 35--
96071400
                   44.9N 164.2E 30
96071406
                   45.2N 166.3E 25
96071412
                   46.4N 168.1E 25
96071418
                   47.7N 169.2E 20 ----
96071500
                   49.0N 170.2E 20
```

AVERAGE 32 86 148 188 165 277 # CASES 30 30 30 30 26 24

SUPER TYPHOON EVE (07W)

	WRN	BE	ST TRA	CK		POS	ITIO	N ERR	ORS				NIND	ERRO	DRS	
DTG	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72
				(KT)	• •			•••	•••				-	• • •		
96071006		19.3N	151.5E	15												
96071012			151.0E	15												
96071018			150.5E	15												100
96071100			150.0E	15												
96071106			149.5E	15												
96071112			148.8E	15				-								
96071118			148.0E	20												
96071200				20												
			147.3E													
96071206			146.7E	25												
96071212			146.2E	25												
96071218			145.7E	25												
96071300			145.2E	30												
96071306			144.5E	30												
96071312	1		143.8E	35	20	34	42	58	77	126					-70	
96071318	2	19.6N	142.9E	40	17	26	42	47	49	110	-15	-25	-35	-50	-85	-50
96071400	3	20.1N	142.1E	45	12	28	39	33	50	112	-15	-35	-35	-70	-90	-45
96071406	4	20.5N	141.3E	55	5	27	33	44	62	144	-20	-30	-50	-85	-65	-30
96071412	5	21.0N	140.5E	65	8	24	45	66	95	199	-30	-35	-70	-85	-50	-25
96071418	6	21.5N	139.7E	70	16	33	56	87	128	230	-25	-40	-70	-50	-30	-10
96071500	7	22.0N	138.8E	75	6	6	24	52	86	194	0	-25	-40	0	15	20
96071506	8	22.5N	137.9E	95	6	30	45	61	94	211	-15	-40	-20	5	30	45
96071512	9		136.9E	115	8	5	29	60	75	172	0	-10	20	30	40	75
96071518	10		136.1E		6	17	44	59	63	133	-5	5	20	40	25	85
96071600	11		135.3E		- 8	18	48	79	72	191	-10	25	10	15	-5	35
96071606	12		134.5E		ō	12	13	44	99	212	-5	20	20	0	20	40
96071612	13		133.7E		6	24	38	62	102	174	5	10		-15	35	45
96071618	14		133.0E		16	27	57	92	77	198	5	20	-5	10	35	45
96071700	15		132.3E		5	24	36	88	54	442	5	5	-10	35	30	30
96071706	16		131.6E		11	26	66	70		545				30	30	
96071712								_	120		5	-10	15			25
	17		131.0E		. 6	11	45	54	199	561	0	-15	35	30	30	20
96071718	18		130.6E		13	19	32	120	217	549	-10	10	30	35	30	25
96071800	19		130.4E		0	32	24	111	231	474	0	25	25	20	5	5
96071806	20		130.7E	90	7	16	64	107	181	438	5	35	30	20	10	0
96071812	21		131.0E	65	5	34	36	34	47	59	10	20	20	5	0	-10
96071818	22		131.3E	55	0	38	42	37	38	106	5	10	5	5	0	-20
96071900	23		131.8E	45	0	34	42	27			-5		-15	-15		
96071906	24		132.8E	40	9	27	29				-5		-10			
96071912	25		133.9E	35	28	30	15	_			-5		-10			
96071918	26		135.0E	35	15	5	19	59			-5	-5		-10		
96072000	27		136.0E	35	5	6	43				-5	-5	0			
96072006		34.7N	137.0E	30						•						
96072012		34.6N	138.0E	30												
96072018		34.3N	139.0E	25												
96072100		33.9N	140.0E	25												
96072106		33.3N	141.0E	30						•						
96072112		32.9N	141.9E	35												
96072118			142.8E	40												
96072200			143.8E	40												
96072206			144.9E	35												
96072212			146.0E	35												
96072218			146.9E	30												
96072300			147.6E	30												
30012300		31.21	141,05	30												

```
SUPER TYPHOOM EVE (07W) (CONTINUED)
96072306
              31.5N 148.4E 30
96072312
              32.1N 149.3E
96072318
              33.0N 150.2E
                            30
96072400
              34.2N 151.2E
                            30
              36.0N 153.0E
96072406
                            30
              37.8N 155.1E
96072412
                             30
96072418
              39.6N 157.3E
                            30
96072500
              41.4N 159.0E
                             30
              42.9N 160.5E
96072506
96072512
              44.1N 162.6E
                             30
              45.3N 164.6E
96072518
                            30
96072600
              46.5N 166.8E
                            30
96072606
              47.9N 168.4E
                            30
96072612
              49.5N 170.0E
96072618
              51.0N 172.0E
                             30
              52.6N 174.5E
96072700
                            30
96072706
              54.0N 178.0E
                            30
              55.0N 178.0W
96072712
                            30
96072718
              56.0N 174.0W
                            30
                     AVERAGE
                                   9
                                       23
                                            39
                                                  65 101 254
                      # CASES
                                  27
                                       27
                                            27
                                                  24
                                                      22
                                                            22
TYPHOON FRANKIE (08W)
         WRN
                  BEST TRACK
                                        POSITION ERRORS
                                                                       WIND ERRORS
  DTG
         NO.
               LAT LONG WIND 00
                                       12
                                           24
                                                 36
                                                     48
                                                            72
                                                                 00 12 24 36 48 72
                            (KT)
96071912
              16.9N 114.7E
                            15
96071918
              16.6N 115.2E
                            15
96072000
              16.4N 115.7E
                             15
              16.0N 115.7E
96072006
                            20
96072012
              16.0N 115.2E
                            25
96072018
              16.3N 114.5E
                            25
96072100
              16.8N 113.8E
                            25
                                  18
                                       28
                                            74
                                                111
                                                     134
                                                          165
                                                                  0
                                                                      5
                                                                        10 -5 -30 -40
96072106
              17.3N 113.2E
                                   5
                                       36
                                            74
                                                 94
                                                      110
                                                           188
                                                                 -5
                                                                      0
                                                                          5 -20 -45 -30
                            30
              17.7N 112.5E
                                            73
                                                                          0 -25 -60 -15
96072112
                            30
                                       39
                                                100
                                                     140
                                                           281
                                                                 -5
              18.1N 111.7E
                                  25
                                       74
                                                                  0
                                                                     0
96072118
                            35
                                           102
                                                135
                                                     148
                                                           290
                                                                        -5 -40 -60 -10
              18.5N 110.9E
96072200
           5
                            3.5
                                  20
                                       50
                                            69
                                                 96
                                                     144
                                                           233
                                                                  ۵
                                                                    -5 -25 -55 -35
                                                                                      Ω
           6 18.7N 110.1E
                                       53
                                                                 -5 -20 -45 -60 -30
96072206
                            40
                                  37
                                            82
                                                116
                                                     194
                                                          237
                                                                                      5
96072212
              19.0N 109.7E
                            45
                                  38
                                       81
                                           116
                                                142
                                                     224
                                                           281
                                                                 -5 -25 -55 -35 -15
                                                                                      10
96072218
              19.2N 109.1E
                                       77
                                            91
                                                      201
                                                                -10 -40 -55 -30 -15
                                                148
                                                                -10 -35
96072300
              19.5N 108.6E
                            60
                                   6
                                       16
                                            13
                                                 35
                                                      84
                                                                         -5
                                                                            -10
                                       32
96072306
         10
              19.8N 107.9E
                            75
                                            12
                                                 49
                                                     139
                                                                -10 -20
                                                                          0
                                                                              0
                                                                                  0
96072312
              20.1N 107.2E
                            90
                                  18
                                       30
                                            53
                                                138
                                                     254
                                                                -20
                                                                     0
                                                                          5
                                                                                   5
         11
                                                                              5
              20.3N 106.8E
                                       76
                                                                    15
96072318
         12
                            90
                                  В
                                           143
                                                207
                                                                 -5
                                                                         15
                                                                             10
96072400 13
96072406 14
              20.4N 106.0E
                                       69
                            65
                                  12
                                            55
                                                  49
                                                                  n
                                                                     10
                                                                          5
                                                                              5
              20.2N 105.1E
                            55
                                  42
                                       49
                                            17
                                                                  0
                                                                      5
96072412
              20.2N 104.1E
                            40
96072418
              20.6N 103.2E
                            35
96072500
              21.1N 102.3E
96072506
              21.7N 101.3E
                            20
96072512
              22.5N 100.3E
                            15
                     AVERAGE
                                  21
                                       51
                                            70
                                                110
                                                     162
                                                           240
                      # CASES
TYPHOON GLORIA (09W)
         WRN
                  BEST TRACK
                                        POSITION ERRORS
                                                                       WIND ERRORS
  DTG
         NO.
               LAT LONG WIND 00
                                       12
                                           24
                                                 36
                                                      48
                                                            72
                                                                 0.0
                                                                    12
                                                                         24 36 48
                            (KT)
96071900
               7.1N 136.9E
96071906
               7.6N 136.6E
                            15
96071912
               B.2N 136.2E
                            15
96071918
               8.7N 135.8E
                            15
96072000
               9.1N 135.4E
                            15
96072006
               9.5N 135.0E
96072012
              10.0N 134.4E
                             20
              10.6N 133.7E
96072018
                            20
96072100
              11.2N 132.8E
                            20
96072106
              11.8N 131.8E
                            25
96072112
              12.4N 130.9E
              12.9N 130.1E
96072118
                             30
                                               133 135 166
                                                                -5 -10 -10 -15 -15 -60
           1 13.2N 129.3E 35
                                  51
                                       71 120
96072200
           2 13.5N 128.7E 40
                                      12B
                                           191
                                                     198
                                                           244
                                                                -10 -10 -10 -10 -40 -40
                                  53
                                                186
96072206
```

42 120

3 13.9N 128.2E 45

-5 -5 -5 -5 -10

TYPHOON C	LORI	A (09W)	(CONTI	NUED)												•
96072218	4	14.4N	127.8E	45	16	28	12	34	72	165	0	-5	-5	-5	-5	20
96072300	5	14.9N	127.5E	50	18	37	78	85	102	212	0	0	5	-10	0	20
96072306	6	15.5N	126.8E	55	24	82	103	125	146	195	0	0	0	-5	5 ู	20
96072312	7	16.0N	126.0E	60	6	12	25	46	106	166	-5	-5	-10	-5	10	35
96072318	8	16.5N	125.1E	65	21	24	30	66	122	200	-5	-10	-10	0	15	50
96072400	9	16.9N	124.5E	70	23	42	75	140	171	173	-5	-20	-10	0	15	35
96072406	10	17.4N	123.9E	80	0	13	45	105	133	216	-5	-10	0	10	20	45
96072412	11	17.8N	123.4E	90	0	24	16	52	32	236	-15	.0	10	25	15	60
96072418	12	18.4N	122.9E	90	6	0	30	36	40	189	0	15	25	10	15	50
96072500	13	19.0N	122.4E	90	12	54	60	32	62		0	15	25	20	25	
96072506	14	19.5N	121.9E	90	23	55	78	20	88		0	15	15	30	30	
96072512	15	19.9N	121.5E	90	12	36	89	54	70		0	15	25	40	45	
96072518	16	20.4N	121.1E	90	18	72	140	149	145		0	15	35	55	55	
96072600	17	21.2N	120.8E	90	6	60	97	149			0	20	40	60		
96072606	18	21.9N	120.8E	90	0	95	222	301			0	5	20	50		
96072612	19	23.4N	120.2E	80	16	113	241				-15	10	20			
96072618	20	24.3N	119.1E	70	12	69	102				0	20	20			
96072700	21	24.8N	117.7E	60	0	33					0	20				
96072706	22	25.1N	116.3E	45	21	67					5					
96072712		25.3N	115.0E	30												
96072718		25.4N	114.0E	20												
			AVERAG	E	17	53	90	97	105	191						

AVERAGE 17 53 90 97 105 191 # CASES 22 22 20 18 16 12

SUPER TYPHOON HERB (10W)

	WRN	B	EST TRA	CK		PC	STTIC	N ERR	ORS				MIND	ERR	oks	
DTG	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72
				(KT)				•			•					
96072106		12 3N	151.6E	15												
96072112			151.9E	15												
96072118		-	152.2E	15												
96072200			152.4E	15												
96072206			152.4E	15												
96072212			152.7E	20												
96072212																
96072300			152.7E	25												
			152.5E	25												
96072306	1		152.0E	25	67	111	163	228	329	566	0	0	0	0	-	-15
96072312	2		151.5E	25	106	145	180	271	370	613	0	5	10	10		-15
96072318	3		150.9E	30	133	145	199	294	419	728	0	0	5	0		-25
96072400	4		150.3E	30	103	142	228	292	365	444	0	0	0		-10	
96072406	5		149.5E	35	24	24	96	172	253	364	0	5	0	-5		-30
96072412	6	19.5N	148.9E	35	24	56	135	192	233	317	0	0	-10	-10	-15	-40
96072418	7	20.0N	147.7E	40	32	107	175	238	281	403	5	0	-5	-10	-15	-25
96072500	8	20.2N	146.4E	45	11	55	68	100	153	321	-5	-10	-10	-15	-20	-25
96072506	9	20.2N	145.0E	55	5	17	45	60	132	318	0	-10	-20	-25	-30	-25
96072512	10	20.2N	143.6E	65	0	28	45	46	21	223	0	0	0	-5	-15	-10
96072518	11	20.5N	142.1E	70	33	105	131	153	91	120	0	-10	-10	-15	-15	-10
96072600	12	20.6N	140.6E	75	12	42	60	84	145	283	0	0	0	-15	-10	-5
96072606	13	20.6N	139.0E	85	21	81	180	246	314	449	0	-10	-10	-15	-10	0
96072612	14	20.4N	137.9E	90	29	96	187	254	308	293	-5	-15	-20	-15	-10	0
96072618	15	20.0N	136.7E	100	58	137	235	340	426	404	0	-5	-10	-5	-5	0
96072700	16	19.7N	135.6E	105	5	29	111	189	238	264	0	-10	0	0	0	-10
96072706	17	19.3N	134.7E	115	8	57	123	185	201	173	Ō	0	10	ō	5	-15
96072712	18		133.9E		13	26	18	41	92	173	ŏ	10	10	5	5	-15
96072718	19		133.2E		12	49	90	113	137	199	ŏ	5	5	10	-	-40
96072800	20		132.5E		8	16	18	16	27	66	0	0	10	10	-15	-35
96072806	21		131.8E		8	18	22	61	73	105	0	0	10	5	-20	
96072812	22		131.1E		11	61	91	122	173	196	0	5	5	-10	-25	-40
96072818	23		130.5E		8	70	92	111	154	174	0	10	5	-15	-35	10
96072900	24		129.9E		8	32	55	82	97		0	5	-10			
96072906	25		129.9E		8	28				84	-	_		-	-35	-10
					_		46	107	120	88	. 0	0		-30	-30	15
96072912	26		128.7E		5	20	55	72	79	91	0	-10	-15		-25	25
96072918	27		128.2E		0	5	32	52	98	142	0	-15	-25	-30	20	35
96073000	28		127.7E		11	6	25	54	103	131		-15		-25	0	45
96073006	29		127.1E		8	30	56	89	125	102	0	-15	-20	30	25	55
96073012	30		126.6E	-	0	32	72	133	170	121	0	-15	-15	10	35	55
96073018	31			140	0	60	121	170	184	127	0	-5	40	् 35	45	60
96073100	32		124.8E		6	37	55	37	54		0	0	25	15	5	•
96073106	33	24.2N	123.8E	135	6	29	96	159	162		-5	55	0	15	15	
96073112	34	24.8N	122.7E	130	0	144	96	107	65		0	-15	5	10	15	•
96073118	35	25.0N	121.4E	75	. 8	114	154	171	151		0	-5	5	15	10	
96080100	36	25.4N	120.0E	95	0	32	49	67	91		0	0	5	0	0	
96080106	37		118.6E	70	5	12	5	23			0	0	5	-5		
96080112	38		117.3E	60	16	59	119				0	ō	-10			
96080118			116.3E	50								•				
				••												

```
SUPER TYPHOON HERB (10W) (CONTINUED)
96080200
              27.5N 115.4E 40
96080206
              28.1N 114.5E
                             30
              28.8N 113.8E
96080212
                             30
96080218
              29.5N 113.1E 25
96080300
              30.3N 112.6E
                             20
96080306
              31.0N 112.1E 20
96080312
              31.7N 111.7E
                             20
                      AVERAGE
                                        57
                                   22
                                             99
                                                  139
                                                      179
                      # CASES .
                                  38
                                        38
                                             38
                                                  37
                                                        36
                                                             31
TROPICAL STORM IAN (11W)
         WRN
                  BEST TRACK
                                         POSITION ERRORS
                                                                         WIND ERRORS
  DTG
               LAT LONG WIND 00
         NO.
                                        12 24
                                                 36
                                                      48
                                                             72
                                                                  00
                                                                     12 24 36 48
                            (KT)
96072706
              11.8N 143.7E
                             20
96072712
              12.3N 143.9E
96072718
              13.1N 144.0E
                             30
96072800
              13.9N 143.9E
96072806
              14.6N 143.6E
                             35
              15.3N 143.3E
96072812
                             35
                                       154
                                            364
                                                  484
                                                       529
                                   62
                                                            645
                                                                        0
                                                                               20
                                                                                   35
                                                                                        50
              16.2N 142.9E
96072818
                                       231
                                                            788
                             35
                                  83
                                            418
                                                 514
                                                       610
                                                                  -5
                                                                       -5
                                                                            5
                                                                               25
                                                                                   40
                                                                                        55
              17.1N 142.3E
96072900
           3
                             35
                                  55
                                       244
                                            369
                                                  462
                                                       583
                                                            720
                                                                   Ω
                                                                        a
                                                                           15
                                                                               30
                                                                                   50
                                                                                        65
96072906
              19.0N 141.2E
                             40
                                  62
                                       188
                                            252
                                                 355
                                                       480
                                                                   -5
                                                                        0
                                                                           20
                                                                               35
                                                                                   50
96072912
              21.1N 140.4E
                             40
                                 136
                                       229
                                            294
                                                  402
                                                       498
                                                                   0
                                                                       15
                                                                           30
                                                                               45
                                                                                   60
96072918
              22.8N 139.8E
                             40
                                 188
                                       234
                                            279
                                                 377
                                                       420
                                                                   0
                                                                      10
                                                                           20
                                                                               30
                                                                                   45
96073000
              23.9N 139.4E
                                 144
                                       159
                             35
                                            200
                                                 234
                                                       222
                                                                   0
                                                                        5
                                                                            5
                                                                                5
                                                                                   10
96073006
              25.0N 139.0E
           8
                             30
                                  90
                                       128
                                            196
                                                 177
                                                                   0
                                                                        5
                                                                            5
                                                                               10
96073012
              25.9N 138.6E
                             30
96073018
              27.0N 138.2E
                             25
                                  79
                                       125
                                            119
                                                                   5
                                                                        5
                                                                            5
                                                                               10
96073106 10
              29.3N 137.2E
                             25
                                  60
                                      125 200
                                                                  -5
                                                                        0
                                                                            ٥
96073112
              30.0N 136.5E
                             25
96073118
              30.5N 135.5E
                             20
96080100
              30.9N 134.4E
                             20
96080106
              31.2N 133.3E
                      AVERAGE
                                  96
                                      182
                                           270
                                                 350
                                                       478
                      # CASES
                                  10
                                        10
                                             10
                                                   9
TYPHOON JOY (12W)
         WRN
                  BEST TRACK
                                         POSITION ERRORS
                                                                         WIND ERRORS
 DTG
               LAT
         NO.
                     LONG WIND
                                  00
                                        12
                                                  36
                                                        48
                                                             72
                                                                  00
                                             24
                                                                      12 24
                                                                               36
                                                                                   4R
                            (KT)
96072512
              19.6N 165.2E
                             10
96072518
              19.5N 164.6E
                             10
96072600
              19.4N 164.0E
96072606
              19.4N 163.5E
                             10
96072612
              19.4N 163.0E
                             15
96072618
              19.4N 162.4E
                             15
              19.6N 161.7E
96072700
              20.0N 160.7E
96072706
                             15
96072712
              20.6N 159.8E
                             15
96072718
              21.4N 158.8E
              22.3N 157.8E
96072800
                             15
96072806
              23.1N 156.9E
                             15
96072812
              24.0N 155.9E
                             15
96072818
              24.8N 154.8E
                             20
96072900
              25.8N 153.9E
                             20
96072906
              26.7N 153.4E
                             25
                                      110
                                            223
                                                 306
                                                       367
                                                            441
                                                                       -5
                                                                            0
                                                                              20
                                                                                   40
                                                                                       30
96072912
              27.0N 152.9E
                             30
                                  23
                                       144
                                            248
                                                 345
                                                       401
                                                            529
                                                                       0
                                                                          10
                                                                               20
                                                                                   30
                                                                                       20
96072918
              26.8N 152.3E
                             35
                                  62
                                       168
                                            268
                                                 338
                                                       358
                                                            476
                                                                  -5
                                                                       0
                                                                          10
                                                                              15
                                                                                   25
                                                                                       15
              26.4N 152.2E
96073000
                             35
                                  41
                                       142
                                            283
                                                 341
                                                       359
                                                            382
                                                                   0
                                                                       5
                                                                           5
                                                                               -5 -25
                                                                                      -50
              26.2N 152.5E
96073006
           5
                             35
                                  38
                                        52
                                            112
                                                 153
                                                       189
                                                            296
                                                                   n
                                                                      10
                                                                            5
                                                                              -5 -35 -50
96073012
              26.2N 152.7E
                             35
                                  20
                                        30
                                             51
                                                  73
                                                        93
                                                            155
                                                                   0
                                                                       5
                                                                            0 -20 -40
                                                                                      -50
96073018
              26.3N 153.0E
                                        26
                                             32
                                                  57
                                                        83
                                                            191
                                                                        0
                                                                          -5 -30 -45 -50
              26.6N 153.2E
96073100
                             35
                                  18
                                        12
                                             33
                                                  70
                                                        94
                                                            226
                                                                   0
                                                                       -5 -10 -35 -45 -45
              26.9N 153.1E
96073106
                             40
                                                       140
                                                                  -5 -10 -20 -40 -45 -45
                                  20
                                        69
                                            111
                                                 132
                                                            198
              27.5N 152.9E
96073112
          10
                             45
                                  41
                                        70
                                             76
                                                  61
                                                        63
                                                            19R
                                                                   O
                                                                     -5 -25 -40 -45 -40
96073118
          11
              28.2N 152.6E
                             50
                                  55
                                        85
                                            108
                                                 121
                                                       136
                                                            177
                                                                  -5
                                                                     -20 -30 -40 -45 -35
                                                                          -5 -15 -25 -25
96080100
              28.8N 152.3E
                                                       103
                                        31
                                             30
                                                  66
                                                             49
```

96080112 14

96080118 15

96080200 16

29.5N 152.0E

30.2N 151.9E

30.7N 151.9E

31.1N 152.0E

96080206 17 31.5N 152.4E 75

7 23

7 57 105

63 112

56 119

82 120

0 0

-5

-10

0 -15 -25 -10

-5

-5 -10 -15 -25 -10

-5 -10 -15 -20

0 -5 -10 -15

0 -10 -10 -10

```
TYPHOON JOY (12W) (CONTINUED)
                                                        65
                                                                           0
96080212 18 31.8N 153.0E 75
                                  10
                                        16
                                             35
                                                  44
                                                             46
96080218 19
                                                           109
                                                                           5
                                                                                5
                                                                                    5
                                                                                        5
              31.9N 153.6E 75
                                              7
                                                        42
                                                                   0
                                                                       0
                                        21
                                                  31
                                                                                   10
                                                                                       10
96080300
          20
              32.0N 154.2E
                             70
                                    5
                                         5
                                             10
                                                  23
                                                        7
                                                            124
                                                                   O
                                                                       0
                                                                           5
                                                                               3.0
96080306
              32.0N 154.9E 70
                                             64
                                                  72
                                                        37
                                                                   0
                                                                       5
                                                                           15
                                                                               15
                                                                                   10
                                                  96
                                                        60
                                                                   0
                                                                       5
                                                                           10
                                                                               10
                                                                                   10
96080312
              32.2N 155.1E
                             65
                                   28
                                        58
                                            119
96080318
              32.4N 155.3E
                                   35
                                        76
                                                  64
                                                        56
                                                                   -5
                                                                           5
                                                                                5
          23
                             60
96080400
              32.7N 155.3E
                                        32
                                                                   0
                                                                       5
                                                                            5
                             55
                                   16
                                             11
                                                  68
                                                       181
          24
                                                                            0
96080406
                                                                   0
              33.2N 155.1E
                                   7
                                        24
                                                 191
                                                                        0
          25
                             45
                                             42
              33.7N 154.9E
                                        51
                                                                           5
                                                                                5
96080412
          26
                             40
                                   12
                                             78
                                                 118
                                                                   0
                                                                       5
96080418
          27
              34.1N 154.8E
                             35
                                   25
                                        92
                                            110
                                                                   -5
                                                                       ٥
                                                                            5
96080500
               34.5N 155.0E
                             30
96080506
               34.8N 155.3E
                             30
                                       187
                                                                   0
                                                                        5
                                   49
96080512
               36.1N 156.2E
                            25
96080518
               37.5N 157.1E
                            25
96080600
               39.0N 157.8E
                            20
                      AVERAGE
                                   23
                                        63
                                             96
                                                 130
                                                      143
                                                            206
                      # CASES
                                                             20
                                   28
                                        28
                                             27
                                                  26
                                                        24
TYPHOON KIRK (13W)
                                                                         WIND ERRORS
                   BEST TRACK
                                         POSITION ERRORS
         WRN
 DTG
         NO.
               LAT
                     LONG WIND 00
                                        12
                                             24
                                                  36
                                                       48
                                                             72
                                                                  00
                                                                     12 24 36
                                                                                   48
                            (KT)
               5.3N 155.8E 15
96072800
96072806
               5.5N 155.3E
96072812
               5.7N 154.7E 15
96072818
               5.9N 154.2E
                            15
96072900
               6.1N 153.7E
                             15
               6.3N 152.9E
96072906
                            15
96072912
               6.5N 152.0E
                             15
96072918
               6.8N 151.0E 20
96073000
               7.1N 149.7E
                             20
96073006
               7.4N 1484.E
                            25
               7.6N 1473.E
96073012
                             25
96073018
               7.8N 146.2E
                             25
96073100
               8.0N 145.3E
                            25
96073106
               8.1N 144.6E
                             25
96073112
               8.1N 143.9E
                             20
96073118
               8.2N 143.2E
                             20
               8.4N 142.5E
96080100
96080106
               8.7N 141.6E
                            20
96080112
               8.9N 140.7E
                             20
96080118
               9.3N 139.8E 20
96080200
               9.8N 138.9E
                            20
96080206
               10.4N 138.1E 20
96080212
               11.0N 137.4E
                             20
96080218
               11.6N 136.7E
96080300
               13.1N 135.7E
                             20
96080306
               15.3N 134.7E
                             25
96080312
               17.7N 134.0E
                             25
96080318
              20.1N 133.4E
                                      143 180
                                                196
                                                      185
                                                           141
                             25
                                   30
                                                                       0
                                                                           5
                                                                              15
                                                                                   10
                                                                                        0
96080400
              22.3N 132.3E
                             25
                                  17
                                        87
                                            104
                                                  91
                                                       17
                                                            187
                                                                   0
                                                                       0
                                                                           5
                                                                                5
                                                                                   -5
                                                                                        0
96080406
           3
              23.8N 131.3E
                             30
                                   18
                                       113
                                            188
                                                 276
                                                       354
                                                            562
                                                                   0
                                                                       5
                                                                          15
                                                                               10
                                                                                   10
                                                                                       30
96080412
              24.9N 130.9E 30
                                       142
                                            255
                                                 371
                                                       506
                                                            778
                                                                         10
                                   49
                                                                   0
                                                                                0
96080418
              25.8N 130.7E
                                                      392
           5
                             30
                                   20
                                        44
                                            152
                                                 256
                                                            609
                                                                   0
                                                                           0
                                                                                0
                                                                                        0
96080500
           6
              26.4N 130.5E
                            30
                                        41
                                            151
                                                 281
                                                       420
                                                            640
                                                                       0 -10
                                                                                    0
                                   24
                                                                                        -5
              27.0N 130.4E
96080506
           7
                                       119
                                                                   0 -10 -10
                                                                                0
                                                                                    0
                             30
                                   50
                                            230
                                                 369
                                                      516
                                                            693
                                                                                      -15
                                                                  -5 -25 -20 -20 -10
96080512
              27.5N 130.7E
           8
                            35
                                  19
                                        71
                                            128
                                                 187
                                                      233
                                                            203
                                                                                      -20
```

96080906 23

96081000 26

27.5N 131.1E 45

27.4N 131.4E

27.1N 131.7E

26.7N 132.2E

26.3N 132.6E

25.9N 133.0E

25.4N 133.6E

25.1N 133.9E

24.9N 134.1E

24.8N 134.1E

24.9N 133.8E

25.1N 132.7E

24.6N 131.1E

24.8N 134.0E 75

25.1N 133.4E 80

25.0N 132.1E 80

24.8N 131.6E 80

24.4N 130.8E 80

В

 -15 -25 -20 -20 -15

-5

-20 -10

O -5 -5 -5

Đ

-15 -10

-15 -10

-5 -5

-5 -10

-25

-5

-10

-10

-5 -5

0 -10 -5

0 -10 -10 -5 -10

-5 -15 -10 -5 -10

-5 -20 -20 -15 -10 -10

-5 -15 -15 -10 -10 -10

~5. 0

-10 -15 -10 -10 -15

-5 -5

TYPHOON K	IRK	(13W)	(CONTINU	ED)												
96081006	27		130.7E	85	0	5	18	43	60	101	0	5	10	15	10	10
96081012	28	24.2N	130.5E	85	8	30	36	72	60	143	. 0	5	10	10	10	15
96081018	29	24.3N	130.4E	85	17	47	53	80	47	160	0	5	10	5	10	15
96081100	30	24.5N	130.3E	85	17	39	76	72	52	221	0	0	0	0	5	10
96081106	31	24.8N	130.1E	85	5	33	59	34	48	146	-5	0	-5	0	5	25
96081112	32	25.1N	129.6E	85	8	24	41	48	40	205	-5	-5	-5	0	10	30
96081118	33	25.5N	129.0E	85	6	12	43	70	67	319	-5	-10	-5	0	5	15
96081200	34	25.9N	128.3E	90	0	43	83	107	132	459	-20	-25	-20	-20	-15	20
96081206	35	26.4N	127.8E	95	0	41	84	118	173	489	-20	-20	-15	-10	0	30
96081212	36	26.6N	127.7E	95	0	27	98	147	256	459	-5	0	5	10	25	25
96081218	37	27.2N	127.6E	95	5	42	97	188	333	333	-5	0	0	15	10	-10
96081300	38	27.8N	127.8E	95	0	55	89	180	326	422	-5	0	5	25	25	20
96081306	39	28.5N	128.1E	95	0	52	93	206	282	371	-5	0	10	30	30	20
96081312	40	30.0N	128.8E	95	6	50	57	131	152	149	-5	-5	10	25	5	10
96081318	41	31.1N	129.3E	95	0	34	102	151	111		0	-5	10	15	5	
96081400	42	32.2N	130.2E	95	5	69	95	46	36		0	10	20	10	5	
96081406	43	33.8N	131.6E	85	0	64	72	48	24		0	15	25	10	5	
96081412	44	35.3N	133.7E	70	7	61	74	78	160		0	5	5	0	0	
96081418	45	37.0N	136.5E	65	33	32	47	4			0	0	-5	-5		
96081500	46	38.6N	139.5E	55	11	51	67	190			0	-5	-5	-10		
96081506	47	40.0N	142.3E	50	29	71	162				0	-5	-5			
96081512	48	41.3N	144.9E	45	10	18	127				0	5	-5			
96081518	49	42.4N	147.2E	45	0	104					0	5				
96081600	50	43, 7N	150.0E	40	18	107					0	-5				
96081606	51		153.5E	40	7						0					
96081612		45.2N	157.0E	40												
			AVERAG	E	13	51	89	124	154	248						
			# CASE	S	51	50	48	46	44	40						

TROPICAL STORM LISA (14W)

	WRN	В	EST TRA	CK		PO	WIND ERRORS									
DTG	NO.	LAT	LONG	WIND (KT)	00	12	24	36	48	72	00	12	24	36	48	72
96080400		15.5N	111.0E	25												
96080406		15.9N	111.7E	25												
96080412		16.4N	112.4E	25												
96080418		16.9N	113.0E	25												
96080500		17.3N	113.4E	25												
96080506	1	17.7N	113.8E	30	72	111	169	243	198		-5	-10	-5	15	20	
96080512	2	18.3N	114.2E	35	39	119	279	343	289		-10	-10	0	15	35	
96080518	3	19.0N	114.8E	40	72	186	311	303	258		-15	-10	5	20	35	
96080600	4	20.1N	115.4E	40	41	146	163	123	102		0	10	25	30	30	
96080606	5	21.4N	116.5E	40	45	87	79	61			0	15	30	30		
96080612	6	22.8N	117.5E	35	55	78	192				0	-5	-5		•	
96080618	7	24.1N	118.0E	30	28	142	140				0	0	-5			
96080700	8	25.0N	117.6E	30	6	36					0	0				
96080706		25.5N	117.3E	25												
96080712		25.8N	117.0E	20												
96080718		26.1N	116.9E	20												
96080800		26.3N	116.6E	15												

TROPICAL DEPRESSION 15W

	WRN	BEST TRACK				PO	SITIO	N ERRO	ORS			W	IND	ERRO	RS	
DTG	NO.	LAT	LONG	WIND (KT)	00	12	24	36	48	72	00	12	24	36	48	72
96081006		29.0N	158.0E	15					:							
96081012		29.7N	157.8E	15												
96081018		30.4N	157.8E	15												
96081100		31.2N	157.9E	15												
96081106		31.6N	158.1E	15												
96081112		32.1N	158.5E	20												
96081118		32.4N	158.9E	25												
96081200		32.7N	159.2E	30												
96081206	1	32.9N	159.5E	30	18	57	115	169			-5	-5	0	0		
96081212		32.9N	160.0E	30												
96081218	2	32.6N	160.2E	30	18	63	72	85			0	0	0	0		
96081300		32.2N	160.3E	30												
96081306	3	31.8N	160.5E	30	12	54	82	139			0	0	0	0		
96081312		31.6N	161.1E	30												
96081318	4	31.4N	161.6E	30	15	39	58	91			- 0	0	0	0		
96081400		31.3N	162.0E	30		•										
96081406	5	31.3N	162.4E	30	13	62	116	178	. :		0	0	0	0		

```
TROPICAL DEPRESSION 15W (CONTINUED)
96081412
              31.5N 163.2E 30
96081418
             31.8N 163.8E
                                             80
                                                  99
                                                                          0
                                        54
96081500
               32.1N 164.5E
                             30
96081506
              32.4N 165.2E
                             30
                                  13
                                       24
                                             34
                                                  60
                                                                      0
96081512
               32.7N 165.9E
                             30
96081518
              33.2N 166.5E
                                  20
                                        25
                                             54
96081600
               33.7N 167.1E
                             30
96081606
              34.1N 167.6E
                             30
                                  13
                                        59
                                             68
                                                                 -5
                                                                      5
                                                                          0
96081612
               34.4N 168.2E
                             25
96081618
               34.8N 168.7E
                             20
96081700
               35.6N 169.1E
                             20
96081706
               36.6N 169.6E
                      AVERAGE
                                  16
                                        49
                      # CASES
TROPICAL STORM MARTY (16W)
         WRN
                   BEST TRACK
                                        POSITION ERRORS
                                                                       WIND ERRORS
  DTG
         NO.
               LAT
                     LONG WIND
                                 00
                                       12
                                            24
                                                 36
                                                       48
                                                                 00
                                                                             36
                                                                     12
                                                                         24
                            (KT)
96081112
              22.9N 108.4E
                            15
96081118
              22.1N 108.4E
                             15
96081200
              21.6N 108.3E
96081206
               21.3N 108.2E
96081212
              21.1N 108.0E
96081218
               21.0N 107.7E
96081306
              20.6N 107.3E
                                           140
                                                                -10 -25 -10
                             35
                                  25
                                                220
96081312
               20.5N 107.1E
                             40
96081318
              20.3N 106.8E
                             50
                                        68
                                           130
                                                                          0
                                                                             10
96081400
              20.2N 106.5E
96081406
              20.2N 106.1E
                             40
96081412
              20.1N 105.7E
                            30
96081418
              20.2N 105.3E
                             30
96081500
              20.3N 104.9E
                            25
96081506
              20.3N 104.5E
                            20
96081512
              20.3N 104.0E
96081518
              20.3N 103.6E
96081600
              20.3N 103.3E
96081606
              20.3N 103.0E
96081612
              20.3N 102.7E
96081618
              20.4N 102.4E
96081700
              20.4N 102.1E
96081418
              29.8N 178.9W
96081500
              29.4N 178.6W
96081506
              29.1N 178.7W
                             25
              28.8N 179.0W
96081512
96081518
              28.3N 179.3W
                            25
96081600
              27.8N 179.7W
                            25
96081606
              27.7N 179.7E
96081612
              27.5N 179.0E
96081618
              27.5N 178.0E
96081700
              27.4N 177.1E
                     AVERAGE
                                  17
                                       51 105 205
                      # CASES
                                   3
                                        3
                                             3
TROPICAL DEPRESSION 17W
         WRN
                  BEST TRACK
                                        POSITION ERRORS
                                                                       WIND ERRORS
  DTG
                    LONG WIND
         NO.
               LAT
                                  00
                                                           72
                                                                 00 12 24 36 48 72
                                       12
                                                36
                                           24
                                                      48
                            (KT)
96081312
              29.6N 176.5E
96081318
              29.8N 177.1E
96081400
              30.2N 177.9E
                            30
                                   0
                                       90 126 237
96081412
              30.0N 179.3W
                                  13
                                       80 210 376
                            25
              29.4N 178.6W
96081500
                            25
96081506
              29.1N 178.7W
96081512
              28.8N 179.0W
96081518
              28.3N 179.3W
              27.8N 179.7W
96081600
96081606
              27.7N 179.7E
                            25
96081612
              27.5N 179.0E
                            25
              27.5N 178.0E
96081618
                            25
96081700
              27.4N 177.1E
                     AVERAGE
                                       85 168 307
```

CASES

2

2

TYPHOON NIKI (18W)

	WRN	Bi	EST TRA	СК		PO	SITIC	N ERF	ORS			5	IIND	ERR	ORS		
DTG	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72	
				(KT)													
96081312			155.8E	15													
96081318			154.3E	15													
96081400			152.8E	20													
96081406			151.0E	20													
96081412			148.8E	20													
96081418			147.2E	20													
96081500 96081506			145.2E	20 20													
96081512			143.4E 142.0E	20													
96081518			142.0E	20													
96081600			139.0E	20													
96081606			137.5E	20													
96081612			136.0E	15													
96081618			135.3E	25													
96081700		13.5N	134.8E	20													
96081706		14.7N	134.2E	25													
96081712		15.7N	133.3E	25					•								
96081718		16.4N	132.1E	20													
96081800	1	17.2N	130.8E	30	16	80	157	198	259	382	0	0	5	-5	5	-15	
96081806	2		129.3E	35	24	79	136	167	244	393	-5	0	_	-10	_	-20	
96081812	3		128.0E	35	33	83	131	222	324	459	-5		-15	_	-15		
96081818	4		126.8E	35	30	64	126	232	330	474	_			-	-30		
96081900	5		125.5E	35	8	30	69	127	172	210	0				-50		
96081906	6		124.2E	45	0	12	86	135	152	175	0				-45		
96081912	7 8		123.1E	55	5	82	150	173	188	170	0			-35		10	
96081918 96082000	9		121.6E 120.0E	60 55	23 26	89 45	141 67	144	137 87	123 131	0	-20		-		25.	
96082006	10		118.4E	65	16	41	62	74	90	132	_	-15 -20			-5 0	45 60	
96082012	11		116.8E	75	13	24	45	64	66	82	-10	-20	-23	10	30	60	
96082018	12		115.3E	80	31	62	92	100	110		-5		-10	10	35		
96082100	13		114.0E	85	5	29	41	62	71		-10	-5	10	5	40		
96082106	14		112.7E	90	5	23	38	65	77		0	5	5	25	45		
96082112	15	17.8N	111.4E	90	6	12	33	45	30		ō	Ō	20	45	45		
96082118	16	18.1N	110.3E	95	13	11	29	34			-5	0	25	30			
96082200	17	18.5N	109.2E	85	8	18	36	17			-5	15	15	15			
96082206	18	19.0N	108.2E	80	18	18	16				0	15	30				
96082212	19		107.1E	75	21	49	28				0	25	30				
96082218	20		106.0E	65	0	41					0	15					
96082300	21		104.9E	45	12	30					0	15					
96082306			103.9E	30													
96082312		20.8N	103.2E	20													
			AVERA	3E	15	44	79	114	156	249							
			# CASI		21	21	19	17	15	11							

20 1 1942 ALMA 1

TYPHOON ORSON (19W)

	WRN	BI	EST TRA	CK		POS	SITION	ERR	OR\$			M	IIND	ERRO	RS	
DTG	NO.	LAT	LONG	WIND (KT)	00	12	24	36	48	72	00	12	24	36	48	72
96081400		14.8N	1763E	15												
96081406		14.8N	1754E	15												
96081412		14.9N	1743E	15												
96081418		14.9N	1727E	15												
96081500		15.0N	1711E	15												
96081506		15.1N	1696E	15												
96081512		15.2N	1680E	15												
96081518		15.3N	1664E	20												
96081600		15.4N	1648E	20												
96081606		15.5N	1630E	20												
96081612		15.6N	1611E	20												
96081618		15.6N	1593E	20												
96081700		15.4N	1575E	20							12					
96081706		15.2N	1559E	20												
96081712		15.0N	1541E	20												-
96081718		15.0N	1523E	20												
96081800		15.1N	1505E	20												
96081806		15.2N	1492E	20												
96081812		15.4N	1479E	20												
96081818		15.6N	1466E	20												
96081900			1453E	20												
96081906			1443E	20												
96081912		17.4N		20												

```
TYPHOON ORSON (19W) (CONTINUED)
               17.8N 143.6E 20
96081918
96082000
               18.2N 143.4E
                               20
96082006
               18.6N 143.2E 15
               19.0N 143.0E 15
96082012
               19.7N 142.8E 20
96082018
96082100
               20.5N 142.7E 20
96082106
               21.3N 142.8E
                               20
                21.7N 142.8E 20
96082112
                                                                       0 0 -5 -15 -10 -30
0 -5 -10 -15 -10 -50
                                                32 50 66 193
35 63 102 254
96082118
               21.9N 142.8E 25
                                          37
                                     24
                                        33
            2 22.2N 142.8E 30
96082200
                                     25
            3 22.5N 142.7E 30
                                                                        0 -10 -20 -15 -20 -65
96082206
                                     12
                                           5
                                                26
                                                     53 129 338
                                                                       -5 -15 -20 -20 -35 -70
96082212
               22.9N 142.6E 35
                                      5
                                          28
                                                56 105 198
                                                              440
               23.2N 142.6E 40
                                          25
                                                     56 113 223
                                                                       -5 -20 -20 -25 -40 -70
96082218
                                                34
                                                                       0 -5 0 -20 -40 -45
0 5 0 -10 -40 -30
0 5 -10 -30 -40 -25
0 -5 -15 -45 -40 -20
              23.4N 142.6E 45
                                                32
                                                    101 203 386
96082300
                                     25
                                          24
                                           40 115
               23.5N 142.6E 55
                                                    219
                                                          335 540
96082306
                                     24
                                         72 158
90 176
               23.7N 142.7E 55
23.8N 142.8E 55
96082312
                                     29
                                                    267
                                                          378 527
            8
                                                          375 496
                                                    276
96082318
                                     22
                                                                        0 -10 -25 -35 -25
                                                                                            0
96082400 10 24.0N 143.3E 55
                                     12
                                          71 158
                                                    241
                                                          314 411
                                         53
                                                                        0 -10 -40 -35 -20
96082406 11
               24.1N 144.0E 65
                                     13
                                               94
                                                    133
                                                          168 195
                                                                        0 -15 -20 -15 0 20
                                         65 130 184
96082412 12
               24.2N 144.7E 75
                                                          221 255
96082418 13
               24.2N 145.5E 80
                                     5
                                          44 104
                                                    164
                                                          183 219
                                                                        0 -25 -15 -5 10 20
                                         17 16
                                                          52 116
                                                                        0 -10 -5 10 25 40
96082500 14
               24.4N 146.5E 100
                                                    22
                                                                       0 0 10 25 40 55
0 0 15 30 40 55
0 5 15 30 35 55
0 10 25 30 40 65
               24.7N 147.3E 115
                                                          44 98
57 114
96082506 15
                                           5
                                                     29
                                                27
                                     10
                                          22
96082512 16
               24.9N 148.2E 115
                                      5
                                                37
                                                      46
                                               0
                                                     24 66 125
42 78 137
67 95 191
96082518 17
               25.2N 148.9E 115
                                     12
                                         5
               25.5N 149.6E 115
                                           В
                                                 8
96082600 18
                                      8
                                                                      -10 0 15 25 45 70
                                        17 39
96082606 19
               25.8N 150.2E 110
                                    13
8
                                                                       -5 5 15 30 45 70
-5 10 15 35 40 60
                                                    84 122 202
72 118 190
               26.0N 150.6E 105
96082612
           20
                                          36
                                                60
               26.2N 150.9E 100
96082618
                                          20
                                                50
           21
                                                                       0 10 20 35 50 70
0 10 30 35 60 70
0 5 30 45 60 60
0 10 0 15 10 0
               26.3N 151.2E 95
26.3N 151.4E 90
                                     6
12
                                          18
                                                44
                                                      66
                                                          96 150
96082700
           22
96082706 23
                                          50
                                                62
                                                     84 104 133
                                    8 26
5 32
8 34
5 44
5 48
21 47
13 31
96082712
               26.3N 151.5E 90
                                                60 120 151 178
           24
96082718
          25
               26.2N 151.7E 90
                                                92
                                                    174
                                                          215 203
               26.3N 151.7E 85
                                                    97 115 173
                                                                        5 10 10 15 20 10
96082800
          26
                                                75
                                                                      0 0 15 10 15 20 10
0 0 15 10 15 -15
0 10 15 20 5 -15
0 20 15 20 5 -30
0 5 15 0 0 -30
0 0 10 -5 -15 -30
-5 5 -10 -10 -25 -45
-5 0 -10 -25 -40 -40
                                                     83 84 149
75 87 144
96082806
           27
               26.4N 151.6E 75
                                                75
               26.4N 151.3E 75
96082812 28
                                                59
                                                     79 100 172
64 87 153
               26.4N 150.8E 75
96082818 29
                                                63
96082900 30
               26.5N 150.1E 65
                                                49
                                    13 18
6 18
8 32
               26.8N 149.5E 55
                                                37
                                                     58 99 188
96082906 31
                                                     78 109
96082912
           32
               27.0N 148.9E 55
                                                42
                                                              263
               27.3N 148.3E 55
                                                     72 113 316
96082918
          33
                                                47
               27.6N 147.7E 45
                                     8 8
16 27
                                                                       0 -10 -10 -25 -40 -35
96083000 34
                                           8 39
                                                     78 133 381
                                                                       0 -10 -20 -35 -30 -10
96083006 35 27.9N 147.1E 45
                                                7
                                                     30
                                                         79 397
                                                    69 147 505
                                     5 17 30
12 15 39
                                                                     -10 -10 -15 -25 -25 0
96083012 36 28.2N 146.5E 55
                                        15
9608301B
          37
               28.6N 145.8E
                               55
                                                39
                                                     90 197 427
                                                                      -10 -20 -30 -25 -20 10
                                     6 15 58 116 183 474
0 26 68 160 241 543
0 36 103 221 371 518
               29.0N 145.1E 55
                                                                      0 -5 -15 -15 -10 15
               29.4N 144.4E 65
                                                                       0 -10 -5 5 5 10
96083106 39
               29.8N 143.9E 65
                                                                       0 -10 -5 10 10 10
96083112 40
                                                                     -5 0 0 5 10 10
0 0 5 0 5 0
-5 -5 0 5 0 0
-10 -5 -5 0 -5 -10
               30.3N 143.5E 80
31.0N 143.2E 80
                                    13 5 77 151 310 443
11 49 115 228 297 487
96083118
          41
96090100 42
                                        62 83 167 180 322
45 55 132 183 468
12 149 213 246 529
96090106 43
               31.6N 143.2E 80
                                     13
96090112
           44
               32.6N 143.9E 80
                                     23
96090118
               33.6N 144.8E 75
                                                                      -10 -10 -5 -10 -10 -10
                                                                         -5 0 -5 0
0 0 0 0
5 0 0 0
0 0 -5 -10
               34.7N 145.8E 70
                                                                       -5 -5
96090200 46
                                     11
                                         103 171 237
                                                          321
               36.3N 147.1E 65
                                              79
96090206 47
                                     15
                                         73
                                                    109 226
                                                                       -5
               38.4N 148.9E 60
40.0N 151.4E 50
96090212
                                          37
                                                66
          48
                                          37 66
32 98
66 130
                                                   139
                                                          252
                                                                       -5
96090218
           49
                                      ٥
                                                    213
                                                          330
                                                                       0
                                                                       0 -5 -5
n 5 5
96090300 50
96090306 51
               41.1N 153.7E 45
                                      4
               42.2N 156.6E 45
                                     12
                                          54 112
                                                   167
                42.7N 159.9E 45
96090312
96090318
               43.0N 163.3E 40
96090400
               43.4N 167.7E 40
               43.7N 172.2E 40
96090406
96090412
                43.9N 176.7E 40
96090418
                44.3N 178.8W 40
                       AVERAGE
                                     12
                                                70
                       # CASES
                                     51
                                          51
                                                51
                                                      50
                                                           49
                                                                 45
```

TYPHOON PIPER (20W)

	WRN BEST TRACK						SITIO	N ERR	ORS			H	IND	ERRO	RS	
DTG	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72
96081900		20.6N	169.6E	(KT) 15												
96081906			168.1E													
96081912		22.2N	166.5E	20												

```
TYPHOOM PIPER (20W) (CONTINUED)
             23.2N 165.0E 20
96081918
96082000
              24.4N 163.3E 20
96082006
              25.7N 161.7E
                           20
96082012
              26.8N 160.3E 20
96082018
              27.9N 158.9E
                           20
              28.2N 157.7E
96082100
                           20
              28.0N 157.0E 20
96082106
96082112
              27.5N 156.8E
                           20
96082118
              26.8N 157.1E
96082200
              26.7N 158.0E
                           25
96082206
              27.0N 158.8E
                           25
96082212
              27.5N 159.5E
                           25
96082218
             28.1N 160.0E
                           25
96082300
          1
             28.7N 160.4E
                           30
                                      28
                                           28
                                                42
                                                     73
                                                        306
                                                                n
                                                                   0 -5 -10 -15 -5
96082306
          2
             29.5N 160.7E
                            35
                                 12
                                      26
                                           59
                                                74
                                                    126
                                                        475
                                                                0
                                                                   0 -5 -10 -10 10
                                                                0 -5 -10 -15 -10 -20
96082312
             30.3N 160.8E 35
                                      47
                                           62
                                                57
                                                     51
                                                         422
             30.9N 160.4E
96082318
                           40
                                 35
                                      82
                                           В9
                                                69
                                                     91
                                                         678
                                                               -5 -10 -15 -15 -10 -15
             31.4N 160.0E 45
                                                                0 -5 -20 -20 -30
96082400
          5
                                      35
                                           75
                                              132
                                                    269
                                 18
             32.0N 159.6E
96082406
          6
                           50
                                 15
                                      45
                                          105
                                              199
                                                    388
                                                               -5 -10 -20 -20 -25
96082412
             32.6N 159.4E
                           55
                                 13
                                      74
                                          168
                                               324
                                                    596
                                                              -10 -20 -20 -25 -25
96082418
          В
             33.2N 159.1E 60
                                 16
                                      60
                                          196
                                               452
                                                    893
                                                              -15 -25 -25 -25 -25
96082500
          9
             34.2N 158.9E
                            65
                                  7
                                      64
                                          213
                                               504
                                                                0
                                                                   5 -5 -15
96082506 10
             35.3N 158.6E 65
                                  7
                                      59
                                          235
                                                                   5 0 -10
                                                                ۵
             36.7N 158.5E
96082512
         11
                            60
                                 17
                                     130
                                          393
                                                                0
                                                                   -5 -10
96082518 12
             38.5N 158.8E
                           60
                                 57
                                     217
                                          584
                                                                0
                                                                   0
                                                                      -5
96082600 13
             40.7N 159.4E
                           60
                                 55
                                                                0
                                     179
                                                                   -5
96082606 14
             43.6N 160.3E
                           55
                                 43
                                     222
                                                                a
                                                                   -5
96082612
              47.5N 161.8E 55
96082618
              52.0N 164.0E
                     AVERAGE
                                 23
                                      91
                                         184 246 311 471
                     # CASES
                                 14
                                      14
                                           12
                                                10
TROPICAL DEPRESSION 21W
         WRN
                  BEST TRACK
                                       POSITION ERRORS
                                                                     WIND ERRORS
 DTG
         NO.
               LAT LONG WIND 00
                                      12
                                         24 36
                                                     48
                                                          72
                                                               00 12 24 36 48
                           (KT)
96082412
             27.0N 155.1E
                           20
96082418
             27.6N 156.6E
                           20
             28.0N 158.0E
96082500
                           20
96082506
             28.6N 159.6E
                           20
96082512
             29.6N 161.0E
                            25
96082518
              30.8N 161.8E
96082600
             31.4N 161.8E
                           25
                                      32 101 161
                                                                    0
                                                                        0
                                                                           -5
              31.7N 161.6E
96082606
                           25
96082612
             32.1N 161.2E
                                 33
                           25
                                     113
                                         170
                                               189
                                                                n
                                                                    n
                                                                        n
                                                                           -5
              32.1N 160.6E
96082618
                           25
96082700
             32.2N 159.9E 25
                                 15
                                      54
                                         133
                                              204
                                                                n
                                                                    0
                                                                        n
                                                                            n
96082706
             32.5N 159.1E
                           25
96082712
          4 32.9N 158.3E 25
                                      86
                                         179
                                                                    0
96082718
              34.0N 157.3E
                           25
96082800
             35.5N 156.6E 25
96082806
             37.1N 156.6E
                           25
96082812
             38.4N 156.9E
                           25
             39.5N 157.5E
96082818
                           25
96082900
             40.2N 158.5E
                           25
96082906
              40.6N 159.5E 25
96082912
             41.1N 160.5E
                           25
96082918
             41.7N 161.5E
                           25
96083000
             42.3N 162.6E
                    AVERAGE
                                      72
                                         146
                     # CASES
TROPICAL STORM RICK (22W)
        WRN
                 BEST TRACK
                                       POSITION ERRORS
                                                                     WIND ERRORS
 DTG
         NO.
               LAT LONG WIND
                                 00
                                      12 24
                                               36
                                                    48
                                                          72
                                                               00 12 24 36 48 72
                           (KT)
96082700
             21.5N 168.0E
                           25
96082706
             22.3N 168.3E
                            30
96082712
             22.8N 169.0E
                           35
96082718
              22.9N 169.9E
                           35
96082800
          1 23.0N 170.8E 35
                                 33 110
                                                                    0
             23.4N 171.7E
96082806
                           30
```

2 24.0N 172.6E 30

-5

0 0

```
TROPICAL STORM RICK (22W) (CONTINUED)
96082818
             24.8N 173.5E 30
96082900
            25.9N 173.9E
                                      30
                                           85 130
                                                                0 -5 -10 -10
96082906
              27.1N 173.8E
                            30
             28.3N 173.6E
96082912
                                                                0 -5 -10 -5
                            30
                                130 192
                                          217
                                              250
96082918
              29.4N 173.2E
                            30
96083000
              30.3N 173.0E
                            35
                                 28
                                     109
                                               180
                                                    188
                                                         297
                                                                0
                                                                    0
                                                                        5
                                                                           -5
                                                                               -5 -10
96083006
             30.7N 172.7E 35
                                      31
                                           36
                                                    155
                                                                           -5
                                                                                0 -10
                                 16
                                                96
                                                                        5
                                                                            0
96083012
              31.0N 172.4E
                            35
                                 46
                                     103
                                          142
                                               185
                                                    232
                                                                0
96083018
             31.2N 172.3E
                                                                    0
                                                                            0
                            30
                                 31
                                      70
                                          134
                                               222
                                                                0
                                                                       -5
96083100
             31.5N 172.3E
                                      62
                                          147
                                                                0
                                                                    0
                                                                       -5
                                                                            0
                            30
                                 17
                                               252
96083106
              31.9N 172.5E
                            30
96083112 10
            32.2N 173.1E 30
                                  7
                                      44
                                           69
                                                                D
                                                                   -5
                                                                        Ω
96083118
              32.5N 174.0E
                            30
              32.9N 175.3E 30
96090100
96090106
              33.3N 176.8E
                            25
              33.7N 178.6E
96090112
                            25
96090118
              34.5N 179.2W
                            30
96090200
              35.5N 177.1W
                            30
96090206
              36.5N 175.0W
96090212
              37.8N 173.1W
                            30
96090218
              39.2N 171.3W 30
96090300
              40.7N 169.6W 30
                     AVERAGE
                                 34
                                      76 122 179 192 270
                     # CASES
                                 10
                                      10
                                           10
                                                 9
SUPER TYPHOON SALLY (23W)
                                       POSITION ERRORS
         WRN
                  BEST TRACK
                                                                     WIND ERRORS
 DTG
         NO.
              LAT LONG WIND
                                00
                                      12 24 36 48
                                                          72
                                                               00 12 24 36 48 72
                           (KT)
96090200
               8.1N 147.7E 15
96090206
               8.5N 146.7E 15
96090212
               8.9N 145.7E
                            15
               9.2N 144.5E 15
96090218
96090300
               9.8N 143.1E 15
96090306
              10.5N 141.6E
                           20
96090312
              11.3N 140.2E 20
96090318
              12.1N 138.4E
                           20
              12.6N 137.1E 20
96090400
96090406
              13.1N 136.1E 20
96090412
             13.6N 135.4E 25
96090418
             14.0N 134.8E
                           25
96090500
          1 14.3N 134.2E
                           25
                                 48
                                      83
                                          132 212
                                                    316
                                                         546
                                                                0 -10 -20 -40 -45 -80
96090506
          2 14.6N 133.6E 30
                                 16
                                      52
                                          132
                                              226
                                                    375
                                                         678
                                                                0 -10 -30 -40 -55 -75
96090512
          3
             15.0N 133.0E
                           35
                                 18
                                      64
                                          166
                                               274
                                                    400
                                                         717
                                                               -5 -15 -35 -45 -60 -60
96090518
          4 15.5N 132.3E
                            40
                                 8
                                      58
                                          114
                                               232
                                                               -5 -25 -35 -45 -75 -45
                                                    331
                                                         621
96090600
             16.0N 131.6E 50
                                 33
                                      87
                                          153
                                               224
                                                    296
                                                         573
                                                                0 -15 -15 -20 -30
                                                                                    0
96090606
             16.7N 130.5E 65
                                                                0 -5 -10 -35 -15
                                 20
                                                    364
                                      57
                                          157
                                               243
                                                         651
                                                                                   25
             17.2N 129.3E 75
96090612
                                 11
                                      45
                                          116
                                              193
                                                    314
                                                         613
                                                                0 0 -15 -25 -15
                                                                                   40
96090618
          8
             17.6N 128.2E
                           80
                                 A
                                      52
                                           97
                                               192
                                                    301
                                                         529
                                                               -5 -10 -40 -20 -10
                                                                                   65
96090700
             18.1N 126.4E 90
                                 22
                                      18
                                           18
                                                69
                                                    128
                                                         295
                                                                0 -15 -20
                                                                           -5
                                                                                   70
96090706
         10
             18.6N 124.8E 100
                                 23
                                      18
                                           30
                                                74
                                                    144
                                                         253
                                                              -10 -40 -15
                                                                            0
                                                                               30
                                                                                   80
96090712 11
             18.9N 123.2E 115
                                           89
                                              151
                                                                0 -20
                                 22
                                      40
                                                    207
                                                                       0
                                                                          15
                                                                                   85
96090718
             19.1N 121.5E 140
         12
                                 23
                                      50
                                          101
                                              177
                                                    253
                                                                0
                                                                  10
                                                                           30
                                                                               65
                                                                      15
96090800 13
             19.4N 119.7E 135
                                  8
                                      11
                                                91
                                                               -5
                                                                      1.5
                                                                           25
                                                                               45
                                           35
                                                    126
                                                                   - 5
96090806
             19.8N 117.7E 130
         14
                                  5
                                      12
                                           49
                                              102
                                                    111
                                                               -5
                                                                  10
                                                                      20
                                                                           40
                                                                               50
96090812 15
             20.2N 115.7E 125
                                  5
                                      35
                                           74
                                               122
                                                    103
                                                               -5
                                                                   10
                                                                       40
                                                                           50
                                                                               50
96090818
             20.6N 113.7E 120
                                      30
                                           90
                                                                0
                                                                   20
                                                                       45
                                              105
96090900
         17
             21.0N 111.5E 110
                                 11
                                      40
                                           94
                                               102
                                                               -5
                                                                    5
                                                                       15
                                                                           20
96090906
             21.5N 109.3E 95
                                      43
         18
                                  0
                                           82
                                                              -10
                                                                       15
96090912
             22.0N 107.2E
                           75
                                  ٥
                                      36
                                           60
                                                              -10
                                                                  10
                                                                       15
             22.6N 105.1E 50
9609091B
96091000
             23.1N 103.5E 35
96091006
             23.4N 102.4E 20
96091012
              23.6N 101.5E 15
                     AVERAGE
                                      44
                                              165
                                                   252
                                                         520
                                 15
                     # CASES
                                 19
                                      19
                                           19
                                                17
                                                          11
                                                     15
TROPICAL STORM 24W
                                       POSITION ERRORS
                                                                     WIND ERRORS
                  BEST TRACK
  DTG
               LAT LONG WIND 00
                                      12 24 36
                                                    48
                                                          72
                                                               00 12 24 36 48
         NO.
                           (KT)
96090600
               8.3N 148.1E 15
96090606
               9.1N 147.6E 15
```

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TROPICAL STORM 24W (CONTINUED)
96090612
              9.9N 147.1E 15
              10.7N 146.6E
96090618
                           15
96090700
              11.3N 145.9E
96090706
              11.8N 145.1E
96090712
              12.3N 144.1E
96090718
              12.9N 142.7E
                            15
96090800
              13.3N 140.9E
                            15
              13.8N 139.0E
96090806
                            15
96090812
              14.2N 137.1E
96090818
              14.5N 135.0E
96090900
              14.7N 133.1E
96090906
           1 14.8N 131.2E
                                       72 145
                                               213
                                                    249
                                                                                    -10
96090912
              14.8N 129.2E
                                 36
                                     118
                                           294
                                                257
                                                     346
                                                          299
                                                                 0
                                                                         10
                                                                                      0
                            25
              14.8N 127.0E
                                      174
                                           269
                                                          293
                                                                 0
                                                                                 10
                                                                                     15
96090918
                                  46
                                                284
                                                     358
                                                                         10
                            25
             15.0N 124.4E
                                 75
                                                          172
                                                                                  5
                                                                                     15
96091000
                            25
                                      255
                                           255
                                                331
                                                     329
                                                                 n
                                                                         5
96091006
              15.9N 121.7E
                            25
                                198
                                      280
                                           253
                                                312
                                                     277
                                                          194
                                                                 0
                                                                     0
                                                                          0
                                                                                  0
                                                                                     20
96091012
             16.5N 118.7E
                                103
                                           175
                                                209
                                                     174
                                                          294
                                                                          0
                                                                              0
                                                                                      0
96091018
              16.8N 117.7E
                            25
                                  49
                                     120
                                           193
                                                187
                                                     206
                                                          342
                                                                          0
                                                                           -10
                                                                                  0
                                                                                      0
              16.8N 116.7E
                                 39
                                     210
                                          270
                                                247
                                                     228
                                                          223
                                                                 0
                                                                    -5 -10
                                                                            -5
                                                                                 10
96091100
                            25
              16.3N 114.9E
                                                                    -5 -10
                                                                             0
                                                                 0
                                                                                 15
                                                                                     35
                                117
                                      283
                                           335
                                                339
                                                     327
                                                          256
96091106
                            30
                                      170
                                                                 0 -10 -15 -10
96091112
          10
              15.7N 112.9E
                            30
                                 79
                                           195
                                                216
96091118
              15.5N 111.5E
                            35
96091200 11
             15.5N 110.7E
                            40
                                  26
                                       72
                                           102
                                                125
                                                               -10 -15 -10
                                                                              0
96091206
              15.8N 110.0E
                                                                -15 -10
96091212
              16.2N 109.5E
                            45
                                  13
                                       34
                                            62
                                                 82
              16.6N 109.0E
96091218
                            40
96091300 13 17.0N 108.5E
                                  13
                                       21
                                            49
                                                 87
                                                                -10
                                                                    -5
                                                                         -5
                            40
96091306
              17.4N 108.0E
                            35
96091312
              17.8N 107.5E
                                  21
                                       33
                                            74
                                                                  0
                                                                     0
                                                                          5
96091318
              18.1N 107.1E
                            30
                                                                  0
                                                                    10
96091400
             18.4N 106.8E
                            30
                                  25
                                       66
              18.6N 106.5E
96091406
                            25
96091412 16 18.7N 106.3E
                                                                  0
                                  79
                                                     278
                                          191
                                               223
                                                          267
                     AVERAGE
                                  63
                                      132
```

TYPHOON TOM (25W)

CASES

	WRN	BE	ST TRA	CK		PO	SITIO	N ERR	ORS			v	IND	ERRO	DRS	
DTG	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72
				(KT)												
96090806			161.8E	15												
96090812			161.3E	15												
96090818			160.5E	15												
96090900			159.8E	15												
96090906			158.6E	15												
96090912			157.5E	15												
96090918			156.4E	20												
96091000			155.5E	20							1					
96091006			154.7E	20												
96091012			153.9E	20												
96091018			153.0E	20						•						
96091100			152.0E	20												
96091106			151.1E	20												
96091112	_		150.3E	25				• •					_	_		_
96091118	1		149.6E	25	16	21	67	88	84	228	0	0	-5	. 0	5	5
96091200	2		149.0E	25	88	134	160	164	139	237	0	-5	-10	-10	-5	0
96091206	3		148.5E	30	24	66	105	131	180	489	0	-5	-5	-5	5	5
96091212	4		148.1E	35	5	33	52	97	178	475	0	-5	-5	0	10	5
96091218	5		147.6E	40	17	23	18	78	188	508	-5	-5	-5	0	5	0
96091300	6		147.1E	45	5	18	37	76	150	286	0	0	0	5	0	-10
96091306	7		146.5E	45	12	32	53	79	153	125	0	0	0	-5	-15	-30
96091312	8		145.7E	50	6	43	72	122	191	211	0	0	5	0	0	. 0
96091318	9		145.0E	50	20	32	73	144	182	225	0	0	0	0	-5	0
96091400	10		144.2E	55	24	45	82	157	162	199	-5 -5	0	-5 -5	-5 -10	-5	5
96091406	11		143.6E	55	13	66	118	114	94	72 278	-5 -5	-5 -10	-10	-10	-5 -10	5
96091412	12		143.4E	55	20	49 82	81 65	90 81	156 140	291	-5 -5		-10	-10	-10	-10 -5
96091418	13		143.4E	60	11		3B	78	133	222		-5		-5 -5	-10	-5
96091500	14		143.6E	65	11	75					0	-	0	_	-	_
96091506	15		144.3E	65	12	28	61	85 97	105 108	88 90	0 -5	-5 -5	0	0	0	10
96091512	16		144.8E	70	17	73	81				-	-	0	5	0	10
96091518	17		145.1E	75	22	30	64	100	106 44	55	-5 0	0	10	5 5	5 10	5
96091600	18		145.3E	75	- 8	40	36	50		184 367	0	0		10	15	5 5
96091606	19		146.0E	75	8	18	37	65	129 178	437	-	5	10	15	15	5 5
96091612	20		146.5E	75	0	18	42	95	251		0	5	5			-
96091618	21	23.1N	146.9E	75	12	30	67	143	221	547	0	5	5	5	-10	-15

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TYPHOON TOM (25W) (CONTINUED)
                                            86 187
                                                                     -5
                                                                           n
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96091700 22 23.6N 147.3E 70
                                   0
                                       18
                                                      330
                                                           625
                                                                   n
96091706 23
              24.1N 147.8E
                            70
                                   5
                                       29
                                             80
                                                 159
                                                      285
                                                           489
                                                                   0
                                                                       0
                                                                         10
                                                                               5
                                                                                   0
                                                                                       5
              24.7N 148.3E 70
                                                                                       0
96091712 24
                                             76
                                                161
                                                           307
                                                                      10
                                                                          10
96091718
          25
              25.3N 148.9E
                                        60
                                                 205
                                                           194
                                                                   0
                                                                      10
                                                                          10
                                                                               5
                                                                                   0
                                                                                       0
                             65
                                   5
                                            111
                                                      227
                                                                          -5
                                                                                      -10
              26.1N 149.6E
                                                                       0
                                                                             -10
                                                                                   -5
96091800
          26
                                                 147
                                                           249
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                                       12
                                             65
                                                      186
                                                                                  -5
              27.0N 150.2E
                                                                       0
                                                                          -5
                                                                              -5
                                                                                     -10
96091806
          27
                            55
                                   0
                                        48
                                             52
                                                  90
                                                      114
                                                           114
                                                                   0
96091812
          28
              27.9N 151.2E
                             55
                                   0
                                       30
                                             60
                                                  46
                                                       44
                                                            54
                                                                   n
                                                                       n
                                                                          -5
                                                                               n
                                                                                  -5
                                                                                     -10
96091818
          29
              28.8N 152.5E 55
                                  15
                                       88
                                             54
                                                  15
                                                       53
                                                           169
                                                                   0
                                                                       0
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                                                                               0
                                                                                  -5
                                                                                     -10
              30.3N 153.2E
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                                                  19
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96091900
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              31.7N 154.3E
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96091906
          31
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96091912
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                                                                           0
96091918
          33
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                                                 244
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                                                                   0
                                                                       0
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96092000 34
                                  25
                                            64
                                                 132
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96092006
          35
              34.9N 160.7E
                             45
                                  61
                                       R7
                                           119
                                                                       O
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96092012
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96092018
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96092100
              37.3N 164.5E
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              38.0N 165.6E
96092106
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              38.8N 166.7E
96092112
                             45
96092118
              39.6N 168.2E
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96092200
              40.7N 170.0E
                             45
96092206
              42.2N 172.2E
                      AVERAGE
                                  16
                                        48
                                             75
                                                115
                                                     161
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                      # CASES
                                  35
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                                                       34
SUPER TYPHOON VIOLET (26W)
                  BEST TRACK
                                         POSITION ERRORS
                                                                        WIND ERRORS
                                                                    12 24 36 48
 DTG
         NO.
               LAT LONG WIND
                                  00
                                       12
                                            24
                                                  36
                                                       48
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                                                                 00
                            (KT)
96090918
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96091000
              14.1N 137.0E
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96091006
              14.6N 135.9E
              14.9N 134.8E
96091012
                             15
96091018
              15.2N 133.7E
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96091100
              15.5N 132.9E
                             20
              15.7N 132.2E
96091106
                             20
96091112
              15.8N 131.7E
                             25
96091118
           1 15.9N 131.3E
                             25
                                       77
                                             88
                                                 116
                                                                     -5 -10 -45
96091206
           2 16.1N 130.4E 35
                                                                    -5 -40 -55
                                       42
                                             62
                                                  93
              16.2N 129.7E
                                                  37
                                                                    -30 -35 -45 -45
96091218
           3
                             35
                                       24
                                             58
                                                       23
                                                          107
           4 16.2N 129.5E
96091300
                                       24
                                                        8
                                                           29
                                                                    -15 -10 -15 -15
                             45
                                  18
                                             24
                                                  11
                                                                   0
                                                                                      -35
96091306
              16.3N 129.3E
                             65
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                                       17
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                                                       29
                                                            66
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                                                                                       0
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96091312
                             75
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                                       23
                                             40
                                                  40
                                                       51
                                                           119
                                                                  0
                                                                     10
                                                                         15 15
                                                                                   5
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96091318
           7
                             75
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                                             41
                                                  49
                                                       74
                                                           170
                                                                  0
                                                                       0
                                                                         10 10 -10
                                                                                      15
96091400
           В
              16.5N 128.7E
                             80
                                  23
                                       44
                                                  90
                                                      143
                                                           275
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                                             64
                                                                                      25
96091406
             16.7N 128.5E
                                                                         10 -10
           9
                             90
                                  16
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                                                           339
                                                                                      35
96091412
          10
             17.1N 128.2E
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                                       53
                                                  59
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                                  16
                                            30
                                                      118
                                                           273
                                                                                   0
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              17.5N 127.8E 95
96091418
          11
                                   5
                                       11
                                            20
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                                                                      -5 -15
                                                  56
                                                       99
                                                           202
                                                                             -5
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                                                                                      45
96091500
              17.9N 127.4E 100
          12
                                   0
                                       34
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                                                109
                                                      146
                                                           223
                                                                  0 -10 -15
                                                                             -5
                                                                                  20
                                                                                      45
96091506
              18.3N 127.1E 105
          13
                                   8
                                       17
                                             62
                                                115
                                                      166
                                                           203
                                                                  0
                                                                    -20 -10
                                                                              5
                                                                                  25
                                                                                      35
96091512 14
              18.8N 126.8E 115
                                   0
                                       22
                                            79
                                                134
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                                                           212
                                                                  0 -10
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                                                                             25
                                                                                  35
                                                                                      45
96091518
          15
              19.3N 126.6E 130
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                                            81
                                                 150
                                                      164
                                                           192
                                                                  -5
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                                                                         15
                                                                              30
                                                                                  35
                                                                                      45
96091600 16
              19.8N 126.5E 130
                                   8
                                       53
                                           113
                                                168
                                                      175
                                                           157
                                                                        25
                                                                             30 35
          17
              20.2N 126.5E 125
96091606
                                  20
                                       71
                                           139
                                                 170
                                                      158
                                                           217
                                                                  0
                                                                     10
                                                                         20
                                                                             30
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              20.6N 126.7E 125
96091612 18
                                  12
                                       62
                                           128
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                                                      182
                                                           283
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                                                                         25 30 35
                                                                                      20
96091618
              20.9N 127.0E 115
          19
                                       30
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                                                                     10 15 10 10 -20
                                  11
                                                12B
                                                           265
              21.4N 127.7E 105
96091700
          20
                                   5
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                                             42
                                                  79
                                                      127
                                                           300
                                                                  0
                                                                      5
                                                                          0
                                                                              5 -15 -20
96091706 21
              21.8N 128.3E 100
                                   0
                                            24
                                                  53
                                                      109
                                                           203
                                                                  0
                                                                     10
                                                                          0
                                                                              5 -10 -10
                                        5
96091712 22
              22.2N 129.0E
                            95
                                   5
                                             31
                                                  36
                                                       60
                                                            36
                                                                  0
                                                                       5
                                                                         10
                                                                             -5 -10
                                                                                      -5
             22.6N 129.6E
96091718 23
                             90
                                       22
                                                  69
                                                       76
                                                            32
                                                                  0
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                                                                             -5 -10
                                             36
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96091800
         24
              22.9N 130.0E
                             90
                                        8
                                             8
                                                  37
                                                       61
                                                                  0
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                                  16
                                                            29
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96091806
              23.2N 130.5E
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         25
                             90
                                   5
                                       16
                                             30
                                                  37
                                                       46
                                                            27
                                                                  0
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                                                                            -5 -10
                                                                                       n
96091812 26
             23.3N 131.0E
                            R O
                                   a
                                       28
                                             33
                                                  65
                                                       64
                                                            63
                                                                  0 -10 -15 -20 -15 -10
96091818
          27
              23.7N 131.4E
                             80
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                                                  96
                                                       99
                                                            74
                                                                  0
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96091900
              23.9N 131.6E
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                                             30
                                                  31
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                                                           128
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96092018 35

96092100 36

96092106 37

96092006 33 25.5N 132.3E 90

96092112 38 29.2N 136.2E 75

24.0N 131.8E

24.2N 132.0E

24.6N 132.1E

25.0N 132.2E

26.1N 132.9E

28.2N 135.0E

26.7N 133.5E 80

27.3N 134.2E 80

5 20

6 37

0 34

5 58

8 43

62 105

84 135

21 282

42 366

57 338

87 187

84 187

76 263

68 277

0 -5

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-5

-5 -10

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-5 10

0 15

-10 -15

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-5

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SUPER TYPHOON VIOLET (26W) (CONTINUED)
                                                    46 111
                                                              0 -10
                                                                     -5
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                                                                                 20
96092118 39 30.9N 137.9E
                           70
                                 0
                                     23
                                          38
                                               48
             32.5N 139.3E 75
                                                    68
                                                                      5
                                                                        10
                                                                            10
                                                                                 20
96092200 40
                                 0
                                     83 137
                                               97
                                                        150
                                                               0
                                                                0
96092206 41
             34.9N 140.9E 80
                                     56
                                          79
                                               63
                                                    71
                                                               ۵
                                                                  5
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                                                                        15
                                                                             15
96092212 42
             37.1N 142.7E
                           75
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                                     42
                                          50
                                               55
                                                    66
                                                               0
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                                                                     10
                                                                         15
                                                                             15
96092218 43
            39.3N 144.6E 70
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                                                                 10
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             41.5N 146.7E
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96092300 44
                                     66
                                              163
             43.0N 148.1E
96092306
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96092312
             44.5N 149.6E
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96092318
             45.8N 151.1E
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96092400
             46.7N 152.4E
                           45
96092406
             47.6N 154.3E
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96092412
             48.4N 156.2E 40
96092418
             48.9N 158.3E 35
             49.2N 160.6E 35
96092500
                    AVERAGE
                                10
                                     36
                                          60
                                               79
                                                    95
                                                        191
                    # CASES
TYPHOON WILLIE (27W)
                 BEST TRACK
                                                                   WIND ERRORS
        WRN
                                      POSITION ERRORS
 DTG
              LAT LONG WIND 00
                                         24 36
                                                  48
                                                        72
                                                              00 12 24 36 48 72
        NO.
                                     12
                          (KT)
             18.7N 107.2E 15
96091600
96091606
             18.5N 107.5E 15
             18.3N 107.8E 15
96091612
             18.1N 108.1E 20
96091618
96091700
             17.8N 108.4E 25
96091706
             17.5N 108.7E
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96091712
             17.3N 109.2E
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          1 17.2N 109.7E 40
                                     74
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96091718
                                31
                                         168 246
                                                        360
96091800
          2 17.2N 110.2E
                           45
                                16
                                     69
                                         145
                                             197
                                                   223
                                                        334
                                                              -5
                                                                  0
                                                                    0
                                                                        -5
                                                                                 10
96091806
          3 17.3N 110.8E
                                                              0
                           50
                                13
                                     90
                                         164
                                              189
                                                   223
                                                        326
                                                                  5
                                                                    -5
                                                                                 15
96091812
          4 17.9N 111.4E
                           50
                                12
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                                          84
                                              147
                                                   24B
                                                        414
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                                                                -5
                                                                    -5
                                                                          0
                                                                                 15
                                          79
96091818
          5 18.6N 111.7E
                           50
                                21
                                     34
                                              164
                                                   266
                                                        426
                                                               0 - 15
                                                                    -5
                                                                          n
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96091900
          6 19.3N 111.8E 55
                                16
                                     25
                                          16
                                               24
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                                                        51
                                                               0
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                                                                                  0
96091906
          7 19.9N 111.5E
                           65
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                                                    62
                                                        115
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                                                                  5 -10
                                                                        -15
                                                                            -10
                                                                                  0
                                 6
96091912
          8 20.1N 111.3E 65
                                13
                                     18
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                                                                    -5 -10
            20.2N 111.1E
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                                                        146
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96091918
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                                     46
                                               86
                                                                     -5
                                                                        -5
                                                                            -15
96092000 10 20.2N 110.6E 65
                                                    77
                                11
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                                          16
                                               46
                                                        95
                                                              0
                                                                  5. 15
                                                                        30 25
                                                                                 30
96092006 11 20.1N 110.1E 65
                                          40
                                                  108
                                                        122
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                                                                  5 20
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                                                                                 10
                                16
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                                               63
96092012 12 20.0N 109.5E
                           60
                                 8
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                                              102
                                                   131
                                                        83
                                                              0
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                                                                         0
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96092018 13 20.0N 108.9E
                           60
                                16
                                     75 158
                                              202
                                                   205
                                                               0
                                                                15 -5 -20 -20
                                                                 10 -5 -20
96092100 14
             19.8N 108.4E
                           60
                                 5
                                     12
                                          45
                                               69
                                                    64
                                                              0
                                                                              0
96092106 15 19.6N 108.0E 55
                                          40
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                                    17
                                               36
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                                                                         0
96092112 16
             19.4N 107.6E 55
                                25
                                     64
                                          72
                                               38
                                                    61
                                                               n
                                                                  5 -15
                                                                         10
             19.3N 107.2E 65
                                          33
                                                              0
96092118 17
                                5
                                     11
                                               87
                                                                  5
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                                                                      5
            19.2N 106.8E
                                          74
                                                              -5 -10
96092200 18
                           60
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96092206 19
             19.0N 106.3E
                           60
                                17
                                     58
                                         108
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                                                                     20
96092212 20
             18.8N 105.7E 60
                                     74
                                         163
                                                             -10
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             18.2N 104.8E
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96092218 21
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                                34
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96092300 22
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96092306
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96092312
             16.5N 101.7E 15
                    AVERAGE
                                16
                                     44
                                          79
                                              107 135
                                                        212
                     # CASES
                                          20
                                     22
SUPER TYPHOOM YATES (28W)
                                                                   WIND ERRORS
        WRN
                 BEST TRACK
                                      POSITION ERRORS
                                             36
              LAT LONG WIND 00
                                         24
                                                    48
                                                         72
                                                              00 12 24 36 48
  DTG
                                     12
                          (KT)
96091706
              8.0N 175.7W 15
96091712
              8.1N 176.9W 15
              8.2N 178.2W 15
96091718
96091800
              B.3N 179.6W 15
96091806
              8.4N 178.9E 15
96091812
              8.5N 177.4E 15
              8.7N 175.9E 20
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8.8N 174.3E 20

8.9N 172.8E 25

9.0N 171.3E 25 9.1N 169.8E 25

9.3N 168.4E 25

9.5N 167.2E 25

9.7N 166.0E 25

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SUPER TYPHOON YATES (28W) (CONTINUED)
96092018
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96092100
              10.6N 164.2E 25
96092106
              11.2N 163.5E 25
              11.9N 163.0E
96092112
                            25
96092118
              12.6N 162.4E
                            25
96092200
              13.4N 161.8E 25
96092206
              14.3N 160.9E 25
96092212
              15.1N 159.8E
                            30
             15.5N 158.6E 35
                                           66 138 204 290
                                                                 0 -25 -50 -40 -45 -40
96092218
                                  21
                                      11
96092300
              15.9N 157.3E 55
                                                                 0 -50 -40 -35 -40 -25
                                  11
                                       64
                                          145 211
                                                     283
                                                          393
             16.2N 156.1E 80
96092306
           3
                                   8
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                                                138
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                                                               -15 -40 -35 -40 -40 -25
96092312
              16.4N 154.9E 115
                                   0
                                       36
                                            84
                                                158
                                                     239
                                                          292
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96092318
           5
              16.4N 153.8E 115
                                   0
                                       17
                                            55
                                                141
                                                     231
                                                          301
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                                                                                  0
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             16.3N 152.7E 115
96092400
                                       12
                                            29
                                                     158
                                                          305
96092406
              16.2N 151.5E 115
                                  11
                                       31
                                            41
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                                                     106
                                                          271
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                                                                         -5
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96092412
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96092418
           9
              16.0N 149.1E 125
                                   0
                                        O
                                            44
                                                     144
                                                          206
                                                               -15
                                                                   -15
                                                                         -5
                                                                              5
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                                                111
                                                                                    15
96092500 10
             15.9N 147.8E 130
                                   0
                                       21
                                            64
                                                 97
                                                     102
                                                          205
                                                                 n
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                                                                                  5 -10
96092506 11
              15.9N 146.6E 130
                                   0
                                       42
                                            89
                                                108
                                                     130
                                                          214
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                                                                    10
                                                                         5
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                                                                                  0 -10
96092512
              16.0N 145.7E 125
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                                            31
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                                                                            10
          12
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                                                 38
                                                      64
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96092518 13
              16.2N 144.8E 125
                                   6
                                       29
                                            29
                                                      94
                                                          359
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                                                                                 -5
                                                 12
96092600 14
              16.5N 144.0E 125
                                            37
                                                      96
                                                                 -5
                                                                         5 -10 -10 -10
                                   0
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                                                 43
                                                          310
                                                                    -5
96092606 15
              17.0N 143.2E 125
                                  11
                                       18
                                            16
                                                 90
                                                     167
                                                          282
                                                                 O
                                                                    10
                                                                         5
                                                                            -5 -10
                                                                                      n
96092612 16
              17.5N 142.4E 125
                                  12
                                       13
                                            28
                                                 94
                                                     171
                                                          187
                                                                 0 10
                                                                        -5
                                                                            -5 -10
                                                                                      n
96092618
          17
              18.1N 141.7E 115
                                   6
                                            66
                                                126
                                                          209
                                                                 0 -10 -20 -25
                                        5
                                                     189
                                                                                -25
              18.8N 141.0E 115
                                                               -10 -20 -20 -25
96092700
                                  12
                                           103
                                               162
                                                     177
                                                          140
                                                                                -20
96092706 19
              19.6N 140.3E 120
                                  13
                                       60
                                           108
                                                135
                                                     140
                                                           90
                                                                -5 -10 -10 -10
96092712 20
              20.2N 139.6E 125
                                                     138
                                                               -10 -10 -15 -10
                                                                                  0
                                                                                     10
                                       42
                                           111
                                                124
                                                           11
96092718 21
              20.6N 139.0E 125
                                  17
                                               137
                                       79
                                           113
                                                     128
                                                               -15 -15 -15
                                                                            -5
                                                                                  0
                                                                                     15
                                                           39
              21.0N 138.6E 125
96092800 22
                                   6
                                       24
                                           24
                                                 52
                                                      31
                                                          177
                                                                 ٥
                                                                     0
                                                                       -5
                                                                             O
                                                                                10
                                                                                     20
              21.4N 138.2E 125
96092806 23
                                   0
                                       21
                                            62
                                                 84
                                                     123
                                                          247
                                                                 Λ
                                                                         0
                                                                             0
                                                                                 5
                                                                                      5
96092812 24
              21.9N 137.9E 125
                                   5
                                       60
                                           136
                                               251
                                                     406
                                                          654
                                                                 0
                                                                     D
                                                                         5
                                                                            10
                                                                                 10
                                                                                      5
96092818 25
              22.7N 137.9E 120
                                           12
                                                     155
                                                          357
                                                                 0
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                                                                        10
                                                                            15
                                                                                15
96092900 26
              23.4N 138.2E 120
                                   0
                                        0
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                                                 42
                                                      80
                                                          245
                                                                 0
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                                                                        20
                                                                            20 20
                                                                                    10
              24.3N 138.6E 110
                                               128
96092906 27
                                  11
                                       43
                                            78
                                                                         0 -5 -10 -15
                                                     174
                                                          327
                                                                     0
                                                                 5
96092912 28
              25.3N 139.1E 105
                                  13
                                       58
                                            72
                                               117
                                                     120
                                                          306
                                                                 0
                                                                         5
                                                                             0 -10 -15
96092918 29
              26.7N 139.6E 100
                                  5
                                       30
                                            91
                                                136
                                                     189
                                                          319
                                                                 ٥
                                                                     5
                                                                         5
                                                                              0 -15 -15
96093000 30
              28.3N 140.4E 90
                                   0
                                       97
                                           258
                                                                            0 -10 -10
                                                315
                                                     417
                                                          456
                                                                 0
                                                                    10
                                                                        10
96093006 31
              29.9N 141.7E
                            85
                                  8
                                      131
                                           215
                                                299
                                                     380
                                                          528
                                                                 0
                                                                     0
                                                                         0 -15 -10 -10
96093012 32
              31.4N 144.0E 80
                                      51
                                                     376
                                                                 0
                                                                         0 -10 -15 -15
                                            98
                                                237
                                                          607
                                                                     5
96093018 33
              32.7N 146.7E 75
                                  7
                                       83
                                           168
                                                276
                                                     385
                                                                 0
                                                                     0
                                                                        -5 -15 -20
              33.6N 149.7E
                           70
96100100 34
                                   0
                                      18
                                           125
                                                240
                                                     321
                                                                 0
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                                                                         0 -15 -15
              34.3N 152.3E 65
96100106 35
                                 23
                                      90
                                          189
                                                302
                                                                 0 -10 -10 -15
96100112 36
                                  38 157
              34.9N 155.2E
                            65
                                           299
                                                426
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96100118 37
              35.4N 158.6E 65
                                      106
                                                               -20 -20 -25
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96100200
              35.9N 162.3E
                            60
96100206
              36.6N 165.7E
                            60
96100212
              37.3N 169.2E
                            60
96100218
              38.4N 172.1E
                            60
96100300
              39.3N 175.3E 55
96100306
              40.5N 178.5E
                            55
96100312
              41.7N 177.5W
                     AVERAGE
                                       43
                                            92 147
                                                    191 288
                     # CASES
                                            37
                                                 36
                                                      34
TYPHOON ZANE (29W)
         WRN
                  BEST TRACK
                                        POSITION ERRORS
                                                                      WIND ERRORS
 DTG
         NO.
               LAT LONG WIND 00
                                       12
                                          24
                                                36
                                                      48
                                                           72
                                                                00
                                                                    12 24 36 48 72
                           (KT)
96092018
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               5.7N 152.7E
96092100
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               5.7N 151.6E
96092106
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96092112
               5.7N 150.5E
                           15
96092118
               5.7N 149.1E 15
96092200
               5.7N 147.7E
                           15
96092206
               5.8N 146.3E 15
96092212
               6.4N 145.4E 15
96092218
               7.4N 144.9E
                           15
96092300
               8.4N 144.5E 15
               9.2N 143.9E
96092306
96092312
              10.1N 142.9E 20
96092318
              11.5N 141.4E 25
96092400
          1 13.1N 139.8E 30
                                 72
                                       47
                                            77
                                                 45
                                                      37
                                                           85
                                                                 0
                                                                     0
                                                                         0 -10 -20 -20
96092406
          2 14.7N 138.1E 30
                                 29
                                       54
                                            96
                                                 92 116
                                                         137
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3 15.6N 136.9E 35

0 53

81 132

0 -15 -25 -25 -10

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TYPHOON ZAME (29W) (CONTINUED)
         4 16.2N 135.5E 40
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96092418
                                    75
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96092500
          5 16.6N 134.0E
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                                                             0 -20 -30 -25 -10 -15
96092506
          6 17.0N 132.5E 50
                               13
                                             152 165
                                                           -20 -30 -30 -25 -10 -15
                                    79
                                       130
96092512
          7 17.6N 131.3E 70
                               24
                                             159
                                                 173
                                                      246
                                                           -15 -25 -15
96092518
          8 18.3N 130.3E 80
                               20
                                    36
                                         82
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                                                 156
                                                      338
                                                                       5
                                                                           5
96092600
          9 19.0N 129.4E 90
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                                    23
                                         24
                                              39 110
                                                      234
                                                           -15 -15 -10 10
96092606
         10
            19.6N 128.4E 100
                                    26
                                         42
                                              88
                                                  104
                                                      206
                                                            -10
                                                               0 20
                                                                       25
                                                                           10
                                                                                 0
             20.1N 127.7E 100
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                                                                 0 20 15 10
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                                         24
                                                 131
                                                     268
96092612
         11
             20.6N 127.0E 105
                                    45
                                         62
                                            102
                                                 189
                                                      268
                                                             0
                                                               20 20 10
                                                                           5
96092618
                               13
         12
                                                             0 10 0 0 -5
                                                                               20
96092700
         13
             21.0N 126.4E 105
                                5
                                    12
                                         16
                                              68
                                                 150
                                                      201
96092706 14
            21.4N 125.9E 95
                                R
                                    16
                                         12
                                             89
                                                 128
                                                      107
                                                             -5 -15 -20 -25 -25 -10
96092712
         15
             21.8N 125.5E 95
                                0
                                    24
                                         63
                                             131
                                                  123
                                                     136
                                                             0 -15 -15 -20 -20
                                                                                0
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             22.3N 125.4E 105
                                        71
                                             99
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96092718 16
                                    12
                                                   81
96092800
         17
             22.9N 125.3E 110
                                В
                                    48
                                       116
                                             124
                                                      165
                                                             0
             23.5N 125.2E 110
96092806
                                Ω
                                    56
                                         92
                                             55
                                                  10
                                                      63
                                                                   5 15 15
                                                                               15
         18
             24.4N 125.5E 110
                                    45
                                         62
                                              22
                                                      199
                                                             0
                                                                 5 10 25 20 15
96092812 19
                                                  30
                                5
                                                             0
                                                               -5
                                                                    0 5
96092818
         20
            25.4N 125.9E 110
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                                       127
                                             184 192
                                                      125
                                                                            5
                                                                                5
                                                                   15 10 10
96092900
         21
             26.3N 126.3E 110
                                В
                                    В3
                                       160
                                            190 181 192
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                                                                Λ
96092906
         22
             26.9N 126.5E 110
                                6
                                    42
                                         73
                                             78
                                                  83
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                                                                10
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                                                                            - 5
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                                             112 136
96092912
         23 27.3N 126.7E 105
                                    41
                                        71
                                                      202
                                                             0
                                                                10 10 15
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                                       100
                                                 148
                                                      217
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                                                                             5 -10
96092918
         24
             27.2N 127.1E
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                                    51
                                             140
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            27.2N 128.1E 85
                                       111
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                                                 204 238
96093000
         25
                                6
                                    48
            27.2N 129.2E 85
96093006
                                                                   0 -10 -20 -20
         26
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                                    44 108
                                             147
                                                  204 321
                                                             0
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                                                                 5 -5 -10 -20 -20
96093012
         27
             27.5N 130.6E
                          80
                                0
                                    30
                                         36
                                              62
                                                 145
                                                       56
                                                             n
                                                               -5 -5 -20 -25
96093018
         28 27.9N 132.2E 75
                                    31
                                         31
                                              62 103
                                                             -5
96100100
         29
             28.5N 134.1E
                          70
                                0
                                    10
                                         47
                                              80
                                                 118
                                                      377
                                                             0
                                                                -5 -5 -25 -30 -15
                                                               0 -5 -15 -15
96100106
         30 28.9N 136.2E 70
                                    13
                                         70
                                            101 131
             29.3N 138.3E
                                         30
                                              24
                                                  47
                                                             0
                                                               -5 -10 -20 -15
96100112
         31
                          70
                               15
                                    36
             29.5N 140.5E
                                         74
                                              86
                                                 146
                                                             -5 -10 -20 -20 -15
96100118
         32
                          65
                               12
                                    55
                                         26
                                                             -5 -10 -20 -15 -10
96100200
         33
             29.5N 142.8E
                          65
                               12
                                    39
                                             86
                                                 244
96100206
         34
             29.8N 145.2E
                          65
                                5
                                     0
                                         20
                                            118
                                                  266
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                                                                   -5
                                                                       -5
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                                                               -5
96100212 35
             30.3N 147.6E
                          65
                               11
                                    15
                                       81
                                             223
                                                 318
                                                             0
                                                                    0
                                                                        n
                                                                             5
96100218
         36
             30.7N 149.8E
                          65
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                                    36
                                        146
                                             292
                                                  363
                                                             0
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                                                                         0
                                                                             0
96100300 37
             31.1N 151.8E
                                  178
                                       154
                                             174
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             31.7N 154.1E
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                                                                     0
96100306
         38
                          60
                                    40
                                             167
96100312 39
             32.4N 156.5E
                          55
                               50 161 192
                                            167
             32.9N 159.4E 50
96100318
96100400
             33.1N 162.4E
                          45
96100406
             33.3N 165.0E 40
96100412
             33.4N 166.7E
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             32.9N 168.2E
96100418
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             32.0N 169.4E
96100500
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             30.8N 170.3E
96100506
                          25
96100512
             29.5N 170.8E
                          25
96100518
             28.4N 171.0E
                          15
96100600
             27.3N 171.0E 15
                    AVERAGE
                                         80
                                            115 152
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TROPICAL STORM ABEL (30W)

CASES

	WRN	B	BEST TRACK LAT LONG WIND 0				SITIO	N ERR	ORS				NIND	ERRO	RS	
DTG	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72
				(KT)												
96100906		12.0N	133.0E	15												
96100912		12.8N	131.7E	15												
96100918		13.5N	130.6E	20												
96101000		13.9N	129.6E	20							. * *	٠.				
96101006		14.2N	128.6E	20												
96101012		14.5N	127.6E	25												
96101018		14.8N	126.6E	25												
96101100	1	15.0N	125.6E	25	61	133	196	189	133	81	0	5	10	-5	-5	20
96101106	2	15.2N	124.6E	25	89	173	213	187	165	59	0	5	0	-10	-5	20
96101112	3	15.4N	123.7E	25	104	159	188	199	190	119	0	5	-15	-5	0	20
96101118	4	15.8N	122.7E	25	70	143	199	224	193	198	0	-5	-15	- 5	0	25
96101200	5	16.3N	121.7E	25	186	138	126	133	165	266	0	-20	-10	5	15	15
96101206	6	17.1N	120.6E	35	129	99	78	140	246	494	-5	-20	-10	5	0	-5
96101212	7	17.7N	119.5E	50	16	70	78	25	145	517	-20	-10	0	15	25	0
96101218	8	18.2N	118.6E	50	12	67	41	63	191	566	-20	-10	0	15	30	0
96101300	9	18.8N	117.6E	45	11	28	72	168	313	606	-15	-5	5	15	15	0
96101306	10	19.4N	116.7E	45	18	71	153	275	450		-15	-10	-5	0	-5	
96101312	11	19.6N	116.0E	40	18	90	198	378	534		-5	10	20	5	-5	
96101318	12	19.6N	115.5E	40	36	115	236	426	582		0	10	20	5	-5	
96101400	13	19.4N	114.9E	35	6	25	66	140	198	199	0	-5	0	-5	-5	-5
96101406	14	19.1N	114.3E	35	24	63	152	236	337	452	0	5	0	0	-5	-5
96101412	15	18.6N	113.7E	35	12	82	170	254	312	383	0	-5	0	. 0	-5	0

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TROPICAL STORM ABEL (30W) (CONTINUED)
96101418 16 18.0N 113.2E 30
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                                                                       0
96101500
              17.2N 112.8E 30
                                                               0
                                                                       0
96101506 17 16.3N 112.4E 30
                                 18
                                      48
                                           94
                                              104
96101512
              15.5N 111.9E 30
96101518 18
              14.7N 111.4E 30
                                 21
                                      58
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                                              178
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                                                                          -5
96101600
              14.0N 111.1E
                            30
96101606 19
              13.7N 110.9E 30
                                                               0
                                                                   0
              13.6N 110.7E
96101612
                            30
96101618 20
              13.6N 110.5E
                                 25
                                      75
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                           30
96101700
              13.7N 110.3E
                           25
96101706 21
             13.8N 110.1E 25
                                 11
                                                               0
96101712
              13.9N 109.9E 20
                     AVERAGE
                                             197 277
                                 43
                                        140
                     # CASES
                                 21
                                      20
                                          19
                                               18
                                                    15
TROPICAL DEPRESSION 31W
         WRN
                 BEST TRACK
                                      POSITION ERRORS
                                                                    WIND ERRORS
  DTG
               LAT LONG WIND
                                00
                                     12 24 36 48
                                                         72
                                                              00 12 24 36 48 72
                           (KT)
               8.9N 158.4E 20
96101000
96101006
               9.0N 157.3E 20
96101012
               9.2N 156.2E 20
96101018
               9.4N 155.3E
                           20
96101100
               9.7N 154.4E 20
              10.2N 153.8E
96101106
                           20
96101112
              11.0N 153.0E 20
96101118
              11.7N 152.3E
                           20
96101200
              12.2N 151.8E
                           20
96101206
              12.8N 151.4E
96101212
              13.4N 151.1E
96101218
              14.0N 150.8E
                           20
96101300
              14.4N 150.5E
                           25
             14.8N 149.8E
96101306
                                     58 106 143 142 233
                           25
                                13
                                                                    10 20
                                                                             30
96101312
            15.2N 149.0E 25
                               104 169 223
                                              263 283 234
                                                               0
                                                                     10 20
                                                                             30
                                                                                  45
96101318
          3
             15.6N 148.3E 25
                                24
                                     - 68
                                         116
                                              104
                                                   164
                                                        243
                                                               0
                                                                   n
                                                                         10
                                                                              20
                                                                                  30
96101400
             16.0N 147.6E 25
                                21
                                     42
                                          36
                                               78
                                                   145
                                                        296
                                                                         10
                                                                                 30
96101406
             16.5N 146.9E 25
                                     29
                                          51
                                 5
                                               66
                                                   102
                                                        212
                                                                     10
                                                                         15
                                                                              25
                                                                                  40
             16.9N 146.2E 25
96101412
                                     29
                                                                   5
                                          34
                                               42
                                                    68
                                                        109
                                                               0
                                                                     10
                                                                         . 15
                                                                              25
96101418
             17.5N 145.3E
                           25
                                20
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                                                                      0
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96101500
             17.5N 144.3E
                           25
96101506
            17.8N 143.5E 25
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96101512
             18.7N 142.7E
             19.5N 142.3E 25
96101518
                                69
                                    104
                                        176
                                             262
                                                   319
                                                                     10
                                                                         15
                                                                             15
96101600 10
             20.2N 141.7E
                                33
                                     83 128
                                                               a
                           25
                                              226
                                                                   O
                                                                      0
                                                                          -5
             20.8N 141.2E
96101606
                           25
96101612 11
             21.5N 140.9E 25
                                50
                                     57
                                         110
                                             215
                                                               n
                                                                   n
                                                                      0
                                                                          5
96101618
             22.4N 140.7E 25
96101700 12
             23.2N 140.5E 25
                                18
                                    105
                                                                   0
96101706
             23.8N 140.3E
96101712 13
             24.3N 139.8E 25
96101718
             24.7N 139.2E 25
96101800
             25.8N 138.7E 20
96101806
             27.0N 138.5E 15
                    AVERAGE
                                30
                                     74
                                         116 156 175 222
                    # CASES
                                13
                                          12
TYPHOON BETH (32W)
                 BEST TRACK
        WRN
                                      POSITION ERRORS
                                                                   WIND ERRORS
 DTG
        NO.
              LAT LONG WIND 00
                                     12 24 36
                                                   48
                                                        72
                                                             00 12 24 36 48
                          (KT)
96100712
             10.9N 162.2E 15
96100718
             11.0N 161.1E 15
             11.0N 160.0E 15
96100800
96100806
             11.1N 158.7E 15
96100812
             11.2N 157.4E 15
96100818
             11.5N 156.2E 15
96100900
             11.9N 154.8E 15
96100906
             12.3N 153.5E 15
96100912
             13.0N 152.1E 15
             13.6N 150.8E 15
96100918
96101000
             14.1N 149.5E 15
96101006
             14.5N 148.6E 15
96101012
             14.7N 147.6E 15
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14.8N 146.7E 15

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TYPHOOM BETH (32W) (CONTINUED)
              14.8N 145.7E 20
96101100
96101106
               14.7N 144.6E
                             20
96101112
               14.2N 143.8E
                             25
96101118
              14.0N 142.7E
                             25
96101200
               14.0N 141.6E
                             25
96101206
               14.2N 140.3E
96101212
               14.6N 139.2E
                             25
96101218
              15.0N 138.1E
                             25
               15.4N 136.5E
96101300
                             25
96101306
              15.5N 134.8E
                             25
96101312
           1 15.6N 133.8E
                             25
                                       115 203
                                                 280 352
                                                            418
                                                                           10
                                                                              10
                                                                                    20
                                                                                        10
96101318
              15.7N 133.0E
                             30
                                   26
                                        82
                                             171
                                                  257
                                                       313
                                                            379
                                                                               10
                                                                                    15
                                                                                         5
           3 15.9N 132.2E
96101400
                             30
                                   13
                                        50
                                             108
                                                  142
                                                       132
                                                            101
                                                                               10
                                                                                    10
                                                                                         0
96101406
              16.0N 131.6E
                             3.0
                                   18
                                        59
                                             91
                                                   98
                                                        90
                                                             91
                                                                    Ð
                                                                                    10 -10
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                                                                               10
96101412
              16.4N 131.1E
                                   42
                                        91
                                             119
                                                       122
                             35
                                                  114
                                                            120
                                                                   -5
                                                                       -5
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                                                                                     5
                                                                                       -20
              17.0N 130.4E
96101418
           6
                             40
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                                             48
                                                   37
                                                        18
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                                                                  -10 -10
                                                                          -5
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                                                                                    -5 -15
96101500
              17.3N 130.0E
                             45
                                   26
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                                                            160
                                                                  -10
                                                                        0
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                                                                               -5
                                                                                     0 -15
96101506
              17.5N 129.5E
                                        33
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                             45
                                                        11
                                                            184
96101512
              17.6N 129.0E
                                        39
                              45
                                   23
                                              45
                                                   45
                                                        34
                                                            128
                                                                   -5 -10 -15 -15 -15 -20
96101518
          10 17.6N 128.2E
                             50
                                   16
                                        33
                                             37
                                                   37
                                                        23
                                                            126
                                                                   -5 -10 -15 -15 -15 -20
              17.6N 127.4E
96101600
          11
                                        18
                                             20
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                             55
                                   21
                                                   58
                                                       120
                                                            167
              17.6N 126.6E
                                                                  -10 -10 -10 -30 -15 -20
96101606
                                                       145
          12
                             60
                                    O
                                         5
                                             12
                                                   86
                                                            201
              17.6N 125.9E
96101612
          13
                             65
                                   18
                                        52
                                             37
                                                   43
                                                       108
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96101618
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                                                   '70
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96101700
          15
              17.7N 124.0E
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                                                  130
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                                             74
                                                       153
                                                            140
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96101706
              17.7N 123.4E
                                        18
                                                  100
          16
                                              42
                                                       121
                                                             62
                                                                        0
                                                                                        30
                                                                               -5
              17.7N 122.8E
96101712 17
                             90
                                        16
                                                       100
                                                                      10 -10
                                             48
                                                   91
                                                            121
                                                                    0
                                                                               -5
                                                                                        40
96101718
              17.6N 122.1E
          18
                             90
                                    0
                                        45
                                             96
                                                  122
                                                       124
                                                            237
                                                                    0
                                                                       -5 - 10
                                                                               -5
                                                                                   15
                                                                                        45
96101800
              17.8N 121.4E
                                    0
          19
                             75
                                        30
                                             82
                                                 101
                                                       131
                                                            291
                                                                   10 -10 -10
                                                                                Ω
                                                                                    25
                                                                                        50
96101806
          20
              18.2N 120.5E
                             75
                                    ٥
                                        21
                                             39
                                                   57
                                                        69
                                                            190
                                                                    0 -10 -10
                                                                               10
                                                                                    30
                                                                                        50
96101812
          21
              18.4N 120.2E
                             80
                                    В
                                        88
                                            136
                                                  186
                                                       258
                                                            350
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                                                                           15
                                                                               35
                                                                                    40
96101818
         .22
              18.8N 119.3E
                             80
                                   30
                                        90
                                            128
                                                  199
                                                       271
                                                            337
96101900
          23
              18.9N 118.3E
                                    0
                                        25
                             80
                                             63
                                                   60
                                                        77
                                                            158
                                                                    0
                                                                       10
                                                                           35
                                                                               45
                                                                                    50
                                                                                        50
              18.9N 117.4E
96101906
                             80
                                        34
                                             88
                                                   95
                                                        77
                                                            204
                                                                       20
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                                                                               45
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                                                                                        45
96101912
              18.7N 116.6E
          25
                                        79
                                            109
                             75
                                   13
                                                  143
                                                       143
                                                            263
                                                                    0
                                                                       25
                                                                           35
                                                                               45
                                                                                    45
                                                                                        30
              18.4N 115.6E
96101918
         26
                                        81
                             65
                                   24
                                             90
                                                   89
                                                       128
                                                            343
                                                                    n
                                                                       15
                                                                           25
                                                                               30
                                                                                    30
              17.6N 114.8E
96102000
         27
                             55
                                   16
                                        73
                                            123
                                                  133
                                                       104
                                                                    a
                                                                       10
                                                                           15
                                                                               20
                                                                                   20
96102006
         28
              17.1N 113.7E
                             50
                                   5
                                        34
                                             36
                                                   72
                                                       141
                                                                    n
                                                                        5
                                                                           10
                                                                               10
                                                                                    10
96102012 29
              16.9N 112.6E
                                        43
                                                  135
                                                                       10
                             45
                                             67
                                                       244
                                                                                   10
96102018
          30
              16.5N 111.5E
                                        18
                                   13
                                             85
                                                 175
                                                       325
                                                                       15
                                                                           10
                                                                                    10
              16.1N 110.5E
                                            116
96102100 31
                             35
                                   0
                                        33
                                                 261
                                                                    0
                                                                        0
                                                                           -5
                                                                                0
96102106
              15.8N 109.8E
                                        83
                                                                    ۵
                                                                        0
                             30
                                            128
                                                 208
                                                                            a
              15.2N 109.2E
96102112
                             30
96102118
              14.5N 108.9E
                             30
                                   60
                                       123
                                                                   -5
                                                                       -5
96102200
              13.9N 108.7E
                             30
96102206
              13.4N 109.0E 25
96102212
              13.1N 109.7E
                      AVERAGE
                                  16
                                        51
                                             81 116 137
                                                            197
                      # CASES
                                  33
                                        33
                                             32
                                                   32
                                                        30
                                                             26
TYPHOOM CARLO (33W)
         WRN
                  BEST TRACK
                                         POSITION ERRORS
                                                                         WIND ERRORS
 DTG
               LAT
                    LONG WIND
                                  00
                                        12 24 36
                                                      48
                                                             72
                                                                  00 12 24 36 48
                            (KT)
96101700
              17.0N 168.0E
                            15
96101706
              16.2N 167.3E
96101712
              15.7N 166.4E
              15.3N 165.2E
96101718
96101800
              15.1N 164.1E
96101806
              15.1N 163.0E
                             15
96101812
              15.1N 161.6E
                             15
96101818
              15.1N 160.5E
                             10
96101900
              15.4N 158.7E
96101906
              15.8N 156.9E
96101912
              16.4N 155.2E
              16.8N 153.7E
96101918
                             20
              17.0N 152.2E
96102000
                             20
96102006
              17.3N 151.5E
                             20
96102012
              17.7N 150.8E
96102018
              18.0N 150.3E
              18.4N 149.8E
                                                 103
                                                        90
                                                            105
                                                                   0
                                                                      -5 -10 -15 -20 -50
96102100
                             25
                                  36
                                        39
                                             74
96102106
              18.8N 149.3E
                             30
                                  30
                                        48
                                             69
                                                  72
                                                        84
                                                             98
                                                                   0 -10 -10 -15 -30 -50
96102112
              19.0N 148.8E
                             35
                                  21
                                        55
                                             96
                                                   98
                                                       131
                                                            318
                                                                   0
                                                                      -5 -10 -15 -35 -25
                                                       122
96102118
              19.1N 148.5E
                             45
                                   29
                                        55
                                             71
                                                   89
                                                            407
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                                                                         -5 -20 -35 -10
           5 19.2N 148.0E
                                                                       -5 -10 -25 -35 -5
96102200
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TYPHOON CARLO (33W) (CONTINUED)
         6 19.3N 147.6E 50
                                               53
                                                   215
                                                        683
                                                              5 0 -15 -35 -35 -5
96102206
                                          33
                                                        772
                                                              0 -5 -25 -35 -25
                                                                                  0
             19.4N 147.1E 55
                                          45
                                             176
                                                   347
96102212
                                 0
                                     28
                                                              0 -15 -30 -30 -10
                                                        68B
                                             197
                                                   318
9610221B
             19.7N 146.3E
                           60
                                 0
                                     23
                                          94
                                                                                  0
96102300
             20.0N 145.5E 65
                                12
                                     91
                                         118
                                             202
                                                   283
                                                        479
                                                              0 -20 -30 -20 -15
                                                             -15 -30 -30 -10
                                                                            -5
96102306
         10
             20.2N 145.2E
                           80
                                20
                                     66
                                         175
                                             291
                                                   398
                                                        508
                                                                                  0
96102312 11
             20.7N 145.0E 90
                                12
                                     40
                                          76
                                             106
                                                   157
                                                        250
                                                              0 -5 10 20 20
                                                                                  Ω
                                                    37
                                                             -10 -5 15
                                                                         10
                                                                              5
                                                                                 -5
96102318
             21.5N 144.9E 100
                                 5
                                     10
                                          24
                                              49
                                                        113
        12
96102400 13
             22.6N 144.8E 105
                                 0
                                     24
                                          44
                                             129
                                                   157
                                                        179
                                                                 10 15 20
96102406 14
                                             109
                                                   102
                                                              0
                                                                 20 25
                                                                        25
             23.8N 144.9E 105
                                     34
                                          60
                                 5
                                                             -10 -10
                                                                     5
                                                                        0
96102412 15
             25.2N 145.1E 95
                                 0
                                     27
                                          86
                                             131
                                                   214
                                                                 0 10 -5
15 10 5
                                                             -10
                                                                              0
96102418 16
             26.8N 145.4E 85
                                11
                                     20
                                          77
                                             140
                                                   195
96102500
         17
             28.4N 146.0E
                           80
                                13
                                     98
                                         200
                                             279
                                                   356
                                                              -5
96102506 18
             30.1N 146.9E 70
                                 0
                                     46
                                          61
                                             109
                                                                 0 -15 -15
96102512 19
             31.9N 148.7E
                           60
                                 8
                                     14
                                               36
                                                                  0
                                                                    -5
                                                                        -10
             33.6N 150.4E 55
                                                                 -10 -10
                                          40
96102518 20
                                11
                                     46
             35.1N 152.3E 55
                                                                 -5
                                                                      0
96102600 21
                                 9
                                     61
                                         130
                                                              -5
96102606
        22
             36.7N 154.4E
                          55
                                 7
                                     97
                                                              0
                                                                  5
96102612 23
             38.2N 157.4E 50
                                15
                                     79
                                                              0
                                                                 10
96102618 24
             39.9N 160.5E
                           45
                                25
                                                               a
96102700
              41.9N 163.6E 40
                    AVERAGE
                                13
                                     47
                                          79
                                             128 199
                                                       398
                    # CASES
                                24
                                     23
                                          21
                                               19
                                                    17
TROPICAL DEPRESSION 34W
                                                                   WIND ERRORS
        WRN
                 BEST TRACK
                                      POSITION ERRORS
 DTG
              LAT LONG WIND 00
                                              36
                                                   48
                                                         72
                                                              00 12 24 36 48
        NO.
                                     12 24
                          (KT)
             10.5N 121.0E 15
96102412
96102418
              9.7N 120.0E 15
96102500
              9.3N 118.7E 15
96102506
              8.9N 117.5E 15
              8.7N 116.2E 15
96102512
              8.4N 114.9E 15
96102518
              8.1N 113.7E 15
96102600
96102606
              7.7N 112.8E 15
96102612
              7.4N 112.1E 15
96102618
              7.0N 111.5E 15
96102700
              6.6N 110.9E 20
96102706
              6.3N 110.3E 25
96102712
              5.9N 109.6E 30
96102718
              5.8N 108.7E 30
96102800
              5.7N 107.7E 25
96102806
              5.8N 106.6E
                           25
96102812
              6.0N 105.5E 25
96102818
              6.5N 104.4E
                           25
96102900
              7.5N 103.7E
                           25
96102906
          1
              8.6N 103.2E 25
                                24 102 114
                                               83
                                                                  0
                                                                     . 5
96102912
              9.5N 102.8E
                           25
96102918
          2 10.4N 102.3E
                                          40
                                     35
                                               57
96103000
             11.0N 101.6E
96103006
            11.2N 100.7E
                                          83
                                             125
96103012
             11.4N 99.6E
                           15
96103018
             11.7N 98.3E
                                79
                                                              -5
                           20
96103100
             12.4N
                    97.3E
                           25
96103106
             13.4N 96.7E
                           25
96103112
             14.6N 97.2E 20
96103118
             15.7N
                    97.9E
                          15
                    AVERAGE
                                     75
                                          79
                                36
                                               89
                    # CASES
                                 4
                                      3
                                           3
                                                3
TROPICAL STORM 35W
                                      POSITION ERRORS
                                                                   WIND ERRORS
        WRN
                 BEST TRACK
              LAT LONG WIND
 DTG
                               00
                                     12 24 36 48
                                                        72 00 12 24 36 48 72
        NO.
                          (KT)
             10.8N 120.8E
96103106
                          15
96103112
             10.8N 120.1E
                          20
96103118
             10.9N 119.4E
                           20
96110100
             11.0N 118.5E 20
96110106
             11.2N 117.7E 20
             11.5N 116.9E 25
96110112
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96110200

96110206

11.9N 116.0E 25

30

49

118 271 394 432

83 176 303 378 327

12.6N 114.4E

2 13.2N 112.7E 35

-5 -10

-10 -10

0 15 30

5 20 10

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TROPICAL STORM 35W (CONTINUED)
                                                            -10 0 10
-10 0 -5
96110212 3 13.6N 111.2E 40
                               98 206 297
          4 14.0N 109.3E 40
                              106 163
96110218
                                        180
96110300
          5 14.4N 107.2E 35
                                6
                                    24
                                         88
                                                             -5 -5
                                                                     0
96110306
          6 14.7N 105.3E 30
                                        219
                                11
                                     60
             14.8N 103.8E
96110312
                          30
96110318
             15.4N 102.6E 25
96110400
             16.4N 102.2E 20
96110406
             17.3N 102.2E 20
                    AVERAGE
                                59
                                   125 227 355
                                                 380
                    # CASES
                                 6
                                           6
SUPER TYPHOON DALE (36W)
                                      POSITION ERRORS
                 BEST TRACK
                                                                   WIND ERRORS
 DTG
        NO.
              LAT LONG WIND 00
                                     12 24 36 48
                                                        72
                                                             00 12 24 36 48 72
                          (KT)
96110200
              9.1N 154.0E 15
96110206
              9.1N 153.7E
                          15
              9.1N 153.4E
96110212
96110218
              9.1N 152.9E
                          15
96110300
              9.2N 152.5E
                          15
              9.4N 152.2E
96110306
                          20
              9.7N 152.1E
96110312
                           25
96110318
              9.9N 152.2E
                           25
96110400
              9.9N 151.9E
                                                            -5 -5 -5 -10 -15 -25
          1 10.0N 152.0E
                                     58 114
                                             152 142 198
96110406
96110412
              9.9N 151.9E
                          35
                                43
                                     61
                                        113
                                             123
                                                  126
                                                       146
                                                            -10 -5 -5
                                                                       -5 -10 -25
          3 10.1N 151.9E
                                                                0
                                                                    0 -5 -5
96110418
                          35
                                64
                                        123
                                             122
                                                  145
                                                       162
                                                            -5
          4 10.2N 152.0E 35
5 10.5N 152.1E 35
96110500
                                71
                                    146
                                        143
                                              95
                                                  115
                                                        72
                                                             -5 -5 -5 -10 -10
96110506
                                87
                                    128
                                              64 126
                                                             -5 -10 -15 -15 -15
                                        100
                                                       106
                                                                                 0
          6 10.7N 152.3E 40
7 10.9N 152.0E 45
                                                              0 -5 -15 -15 -20
96110512
                                4 R
                                     78
                                        106
                                              59
                                                   41
                                                        72
96110518
                                42
                                     85
                                         82
                                              51
                                                   72
                                                        48
                                                             0 -10 -15 -15 -15 -5
96110600
          8 11.3N 151.1E 50
                                48
                                    76
                                         76
                                             58
                                                   99
                                                        74
                                                             -5 -10 -10 -15 0
                                                                                0
96110606
          9 11.5N 150.2E
                          60
                                76
                                    102
                                         64
                                             113 128
                                                        81
                                                             -5 -5 -5
                                                                        0 10 -10
96110612 10 11.6N 149.1E 65
                                42
                                    79
                                       123
                                             155 236
                                                      251
                                                             -5 -5 -15
                                                                       0 10 -20
96110618 11 11.5N 148.4E
96110700 12 11.1N 148.0E
                                             145 159
64 59
                                                            -5 -10 -15
-10 -20 -15
                          70
                                    106
                                         94
                                                                         0 0 -20
                                34
                                                       161
                                                                         0 -15 -20
                          75
                                    16
                                11
                                         18
                                                       137
96110706 13 11.3N 147.7E 80
                                8
                                     63
                                         72
                                             58 26
                                                       99
                                                            -5
                                                                0 15 15 0 -15
96110712 14 11.7N 146.1E
                          90
                                0
                                     45
                                       109
                                             100
                                                   88
                                                       119
                                                              0 10 25 10 -5 -15
96110718 15 11.4N 144.5E 90
                                12
                                     84
                                       105
                                             125 115
                                                       200
                                                              0 10 15 -5 -5 -15
            11.6N 143.3E 90
                                     67
                                         78
                                             123 155
                                                       201
                                                             0 10 0 -15 -5
96110800 16
                                0
96110806 17 11.4N 142.4E 90
                                0
                                     58
                                       114
                                             198 240
                                                       280
                                                             0 -5 -15 -15 -5
96110812 18
            11.7N 141.5E 90
                                     88
                                                       287
                                                              0 -10 -25 -15 -5
                                18
                                        144
                                             228 230
96110818 19 12.3N 140.0E 100
                                     72
                                                              0 -15 -20 -10 -5 10
                                18
                                        156
                                             220 244
                                                       371
96110900 20 12.8N 138.9E 115
                                     66
                                                       473
                                                            -10 -25 -20 -10 5 20
                                Я
                                       148
                                             162 228
96110906 21 13.7N 137.8E 130
                                0
                                    32
                                         64
                                             111 225
                                                       562
                                                              0 -10 -15 -20 -10
                                                                                 5
96110912 22 14.5N 136.6E 140
                                ٥
                                     68
                                         90
                                             162 237
                                                       515
                                                              5 15 20 10 -10
96110918 23 15.7N 135.2E 140
                               21
                                     36
                                         83
                                             176
                                                 253
                                                       626
                                                             10 15 20 10
96111000 24 16.8N 133.8E 140
                                0
                                    92
                                       162
                                             228 286
                                                       555
                                                                    5
                                                                        0
96111006 25 17.5N 132.8E 140
                                0
                                     64
                                             212 264
197 324
                                                                 0
                                       152
                                                       736
                                                              0
                                                                     5
                                                                         5
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96111012 26 18.3N 132.1E 140
                                    74
                                                                     5 15
                               11
                                       149
                                                       924
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                                                                10
                                                                            15
                                                                                25
                                        94
96111018 27 19.3N 131.6E 140
                               11
                                     65
                                             129 275
                                                      907
                                                              n
                                                                10 10 10
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                                                                                20
96111100 28 20.5N 131.3E 130
                                5
                                    20
                                         76
                                             192 388 1048
                                                              0
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                                                                     5
                                                                         0
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                                                                                20
96111106 29 21.7N 131.3E 130
                                    22
                                         87
                                             201 463 1129
96111112 30
            22.7N 131.4E 130
                                         91
                                0
                                    29
                                             220
                                                 345
                                                                    5
96111118 31 23.7N 131.8E 125
                                                                    -5
                                0
                                    17 120
                                                                 0
                                             244
                                                 393
96111200 32 24.9N 132.5E 115
                                0
                                    59
                                        236
                                             425
                                                  612
                                                              0
                                                                 0
                                                                     0
                                                                       10
                                                                             0
96111206 33 26.1N 133.8E 115
                                0 106
                                        257
                                             450
                                                  692
                                                              0
                                                                 -5
                                                                     0
                                                                         5
96111212 34 27.8N 136.4E 105
                                44 164
                                        246
                                             267
                                                              0
                                                                 10 10 10
96111218 35
            29.5N 139.3E 105
                                37
                                   191
                                        272
                                             352
                                                              0
                                                                 20
                                                                    25
                                                                        15
            31.2N 143.9E 90
96111300 36
                                87
                                   129
                                        153
                                                                 15
96111306 37
             32.9N 148.7E
                          80
                                40
                                     9
                                                              0
                                                                 5
                                                                    10
            34.9N 154.3E 70
96111312 38
                                     27
                                15
                                                             -5
                                                                  0
96111318 39 37.4N 160.6E 65
                                61
                                   181
                                                              0
                                                                  5
96111400
             40.7N 167.1E 60
                    AVERAGE
                                26
                                     76 122 171 229
                                                       364
                    # CASES
                                39
                                    39
                                        37
                                             35
                                                   33
                                                        29
TROPICAL STORM ERBIE (37W)
                                      POSITION ERRORS
                                                                  WIND ERRORS
        WRN
                 BEST TRACK
              LAT LONG WIND 00
                                                        72
                                                             00 12 24 36 48 72
  DTG
        NO.
                                    12 24 36 48
                          (KT)
96102900
              7.0N 155.0E 15
              7.0N 154.5E 15
96102906
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TROPICAL STORM ERNIE (37W) (CONTINUED)
96102912
                7.0N 154.0E 15
96102918
                7.0N 153.5E
                              15
96103000
                7.0N 153.0E
                              15
                7.0N 152.5E 15
96103006
96103012
                7.0N 152.0E
                              15
96103018
                7.0N 151.5E
                              15
96103100
                7.0N 151.0E
                              15
96103106
                6.9N 150.4E
                              15
96103112
                6.8N 149.7E
                             15
96103118
                6.6N 148.8E
96110100
                6.4N 147.7E
                              15
                6.1N 146.2E
96110106
                              15
96110112
                5.9N 144.7E
                              15
                5.7N 143.2E
96110118
                              15
96110200
                5.6N 142.0E
                              15
96110206
                5.5N 141.0E
                              15
96110212
                5.5N 140.2E
                              15
96110218
                5.4N 139.4E
96110300
                5.2N 138.3E
                              15
                5.0N 137.1E
96110306
                              15
96110312
                4.9N 136.0E
                              20
96110318
                5.1N 134.9E
                              20
96110400
                5.3N 133.4E
                              20
96110406
                5.5N 132.2E
                              20
                6.0N 131.2E
96110412
                              25
                                    29
                                        127
                                             215
                                                  274
                                                        353
                                                              412
96110418
                6.6N 130.2E
                                                                      0
                                                                         10
                                                                             10
                                                                                  10
                                                                                       0
                                                                                         -10
                                              187
                                                   223
                                                        285
                                                              332
                              25
                                    51
                                        134
96110500
           3
                7.4N 129.2E
                              25
                                    26
                                         48
                                               49
                                                   108
                                                        130
                                                              107
                                                                      0
                                                                          5
                                                                              5
                                                                                   5
                                                                                       0
                                                                                          -5
96110506
                8.1N 128.3E
                              25
                                    25
                                         36
                                               29
                                                    74
                                                         105
                                                               91
                                                                      n
                                                                              O
                                                                                   0
                                                                                      -5
                                                                                          -5
96110512
           5
                8.7N 127.2E
                              30
                                    16
                                         18
                                               71
                                                   112
                                                         101
                                                              108
                                                                      0
                                                                          0
                                                                              0
                                                                                   0
                                                                                      -5
                                                                                           -5
                9.1N 126.3E
                                                                      0
                                                                         -5
                                                                             -5
                                                                                  -5
                                                                                      -5
                                                                                            0
96110518
                              30
                                    23
                                         24
                                               96
                                                   117
                                                         85
                                                              136
                                               96
96110600
                9.5N 125.3E
                              35
                                    24
                                         93
                                                    85
                                                          88
                                                              234
                                                                     -5
                                                                        -10
                                                                             -10
                                                                                 -10
               10.3N 124.7E
                                    43
                                                                     -5
                                                                            -15
                                                                                 -10
                                                                                       -5
96110606
           8
                              40
                                         96
                                              109
                                                    85
                                                         113
                                                              274
                                                                        -10
96110612
               11.2N 123.8E
                              40
                                    18
                                         84
                                              104
                                                          70
                                                                      0
                                                                         -5
                                                                                   0
                                                                                       5
                                                                                           30
           9
                                                    90
                                                              193
                                                                             -5
96110618
          10
               11.7N 122.8E
                              45
                                    18
                                        101
                                              88
                                                    83
                                                          81
                                                              191
                                                                      0
                                                                         -5
                                                                              0
                                                                                   5
                                                                                      20
                                                                                           35
96110700
               12.0N 121.3E
                                         .78
                                              144
                                                   182
                                                         225
                                                                      0
                                                                          0
                                                                              0
                                                                                   5
                                                                                      25
                                                                                           30
                              45
                                    21
                                                              260
                                                                          5
96110706
          12
               12.1N 120.2E
                              50
                                     В
                                        103
                                              183
                                                   237
                                                         291
                                                              381
                                                                      0
                                                                             15
                                                                                  25
                                                                                      40
                                                                                           50
96110712
          13
               12.3N 119.8E
                              50
                                    64
                                        146
                                             209
                                                   300
                                                         365
                                                              479
                                                                      0
                                                                          5
                                                                             15
                                                                                  30
                                                                                      40
                                                                                          30
               12.5N 119.5E
                                   105
                                                                      0
96110718
                                                              381
                                                                          5
                                                                             20
                                                                                  35
                                                                                      35
                                                                                           30
          14
                              50
                                        148
                                             175
                                                   233
                                                         298
               12.7N 119.3E
96110800
          15
                              50
                                    16
                                        197
                                              243
                                                   295
                                                         369
                                                              403
                                                                      n
                                                                          n
                                                                             15
                                                                                 25
                                                                                      20
                                                                                          20
96110806
          16
               13.4N 118.9E
                              50
                                    30
                                         90
                                             216
                                                   259
                                                         311
                                                              308
                                                                      0
                                                                          5
                                                                             20
                                                                                 20
                                                                                      20
                                                                                          20
96110812
          17
               14.1N 118.6E
                              50
                                    13
                                         64
                                              139
                                                   172
                                                        149
                                                               64
                                                                      0
                                                                         10
                                                                             20
                                                                                 15
                                                                                      20
                                                                                          20
               14.8N 118.4E
                              45
                                             127
                                                               90
                                                                      0
                                                                         15
96110818
          18
                                    25
                                         96
                                                   164
                                                        146
                                                                            15
                                                                                 15
                                                                                      20
                                                                                          20
96110900
          19
               16.0N 118.3E
                              40
                                    24
                                        120
                                             171
                                                   182
                                                        186
                                                              186
                                                                     -5
                                                                          0 -10
                                                                                 -15
                                                                                     -15
                                                                                          -15
96110906
               17.3N 117.7E
                              35
                                                                      0 -10 -15 -15
          20
                                    20
                                         36
                                              63
                                                   123
                                                                                     -15
                                                        144
                                                              193
96110912
               17.9N 117.7E
                                    75
                                              232
                                                                     -5 -15 -15 -15
          21
                              35
                                        160
                                                   264
96110918
               18.5N 117.8E
                              40
96111000
          22
               19.2N 117.9E
                              45
                                     ٥
                                         34
                                              102
                                                   118
                                                        138
                                                              215
                                                                     -5
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                                                                                         15
96111006
          23
               19.6N 118.0E
                              45
                                     0
                                         28
                                              73
                                                   164
                                                        193
                                                              279
                                                                     -5
                                                                         -5
                                                                            -5
                                                                                   0
                                                                                      10
                                                                                          15
96111012
               19.8N 118.0E
                                             135
                              45
                                    30
                                         43
                                                  194
                                                        239
                                                              350
                                                                     -5
                                                                         -5
                                                                                 -20
                                                                                     -10
96111018
          25
               20.0N 118.1E
                              45
                                    47
                                         94
                                             181
                                                  229
                                                        254
                                                              423
                                                                      0
                                                                          0
                                                                              0
                                                                                 -15
                                                                                      15
                                                                                          20
96111100
               20.2N 118.1E
                                     0
                                        102
                                                                                 15
          26
                                                   224
                                                        232
                                                              467
                                                                      0
                                                                          0
                                                                              0
                                                                                      15
                                                                                          15
                              45
                                              184
               19.8N 118.5E
96111106
          27
                                         80
                                             148
                                                        120
                                                                      0
                                                                          0
                                                                             10
                                                                                 15
                              45
                                     5
                                                   165
                                                              234
                                                                                      15
                                                                                          15
               19.4N 119.2E
96111112
          28
                              45
                                    12
                                         72
                                              110
                                                    75
                                                         81
                                                              276
                                                                      0
                                                                         -5
                                                                              n
                                                                                  0
                                                                                       n
                                                                                          -5
96111118
          29
               19.3N 120.0E
                              45
                                    39
                                         79
                                              104
                                                   125
                                                        187
                                                              343
                                                                      0
                                                                          5
                                                                              0
                                                                                 -5
                                                                                     -5
                                                                                         -10
96111200
          30
               19.0N 120.6E
                              45
                                     0
                                         64
                                              123
                                                   187
                                                        281
                                                              414
                                                                      0
                                                                          5
                                                                             -5 -10 -15
                                                                                         -10
               18.4N 121.0E 35
96111206
                                    34
                                         62
                                              99
                                                   174
                                                        266
                                                              357
                                                                          0
                                                                             -5 -10 -15
96111212
          32
               17.6N 121.1E
                              35
                                     5
                                        102
                                             179
                                                         321
                                                              350
                                                                      0
                                                                          0
                                                                             -5 -15
                                                   255
                                                                                     -10
                                                                                           0
               16.7N 120.4E
                                                                         -5 -10 -15
96111218
                                                                      0
          33
                              35
                                    18
                                         89
                                              129
                                                   182
                                                        205
                                                              300
                                                                                     -5
               16.2N 119.3E
                                                                         -5 -10 -10
96111300
          34
                              35
                                     8
                                         53
                                             120
                                                   188
                                                        213
                                                              244
                                                                      0
                                                                                     -10
                                                                                           -5
96111306
          35
               15.8N 118.2E
                              35
                                     8
                                         23
                                              21
                                                    59
                                                         96
                                                              159
                                                                      0
                                                                         -5 -10
                                                                                 -5
                                                                                     -10
                                                                                           -5
96111312
          36
               15.5N 117.3E
                              35
                                     0
                                         61
                                              122
                                                   185
                                                        212
                                                              339
                                                                      0
                                                                        -10 -10
                                                                                   0
                                                                                            5
                                                                                       n
96111318
          37
               14.9N 116.2E
                              35
                                         72
                                              107
                                                   154
                                                                      0
                                                                                   0
                                    21
                                                         172
                                                              243
                                                                         -5
                                                                              0
                                                                                       5
                                                                                            0
96111400
          38
               14.1N 115.1E
                              40
                                     0
                                              42
                                                    50
                                                          67
                                                               56
                                                                             10
                                                                                  10
96111406
          39
               13.6N 113.9E
                              40
                                     0
                                         46
                                              105
                                                   128
                                                         143
                                                               95
                                                                      0
                                                                         10
                                                                             10
                                                                                   5
                                                                                       0
               13.0N 112.8E
96111412
          40
                              40
                                     Я
                                         58
                                              82
                                                    90
                                                          93
                                                               34
                                                                      0
                                                                         10
                                                                             10
                                                                                   5
                                                                                       0
96111418
          41
               12.3N 112.3E
                              35
                                    21
                                         43
                                               54
                                                    77
                                                          75
                                                               21
                                                                      n
                                                                          n
                                                                              5
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                                                                                            Ω
96111500
          42
               11.4N 111.6E
                              35
                                     8
                                               63
                                                    67
                                                          82
                                                              173
                                                                      0
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                                                                                  -5
                                                                                       ٥
                                         56
                                                                         -5
                                                                                           -5
96111506
          43
               11.0N 110.8E
                              35
                                    13
                                         32
                                               29
                                                    18
                                                          36
                                                              129
                                                                          0
                                                                               0
                                                                                   0
               10.8N 110.1E
                                                                          0
                                                                               0
                                                                                   0
                                                                                       0
96111512
          44
                                     0
                                         29
                                               51
                                                    45
                                                          23
                                                                      0
                              35
96111518
          45
               10.4N 109.2E
                              30
                                    16
                                         46
                                               71
                                                    69
                                                          35
                                                                      n
                                                                          0
                                                                               5
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96111600
          46
               10.0N 108.3E
                              30
                                     0
                                         13
                                               61
                                                    84
                                                                      0
                                                                          0
                                                                               0
                                                                                   0
96111606
                9.7N 107.3E
                              30
96111612
                9.4N 106.3E
                                     0
                                         42
                                               67
                                                   131
                                                                          0
                                                                               0
                                                                                   0
                              30
                9.4N 105.0E
96111618
                              25
                                                                          0
                                                                             -5
96111700
                9.5N 103.9E
                              25
                                     В
                                         23
                                               84
96111706
                9.6N 102.8E
                             2.5
96111712
                9.8N 101.8E
                              25
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TROPICAL STORM ERWIE (37W) (CONTINUED)
96111718 10.1N 100.8E 25
96111800 10.4N 100.0E 25

AVERAGE 21 72 117 152 175 246 • CASES 48 48 47 42 48

TROPICAL STORM 38W

	WRN	BEST TRACK LAT LONG WIND (KT)				PO	SITIC	N ERR	ORS			W	IND	ERRO	RS		PLATFORM
DTG	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72	
				(KT)													
96110406		21.4N	175.1E	25													
96110412		22.4N	174.9E	.35													
96110418		23.1N	174.3E	40													
96110500		23.5N	173.7E	50													
96110506		23.6N	173.1E	50													
96110512		23.6N	172.5E	45													
96110518		23.7N	172.1E	40													
96110600		24.0N	171.8E	35													
96110606	1	24.3N	171.8E	35	8	68	158	145			-5	-5	-5	-10			
96110612			172.0E														•
96110618	2		172.2E		21	32	115	87			-5	-5	-5	-10			
96110700			172.3E														
96110706	3		172.4E		49	39	112	190			-5	-5	-5	-5			
96110712			171.8E														
96110718	4		170.5E		32	121	196	275			-5	-10	-5	-5			
96110800			169.QE	35													
96110806	5 -		169.3E	35	34	166	282				-10	-10	-10				
96110812			169.8E	30													
96110818			170.2E	30													
96110900			170.4E	25													
96110906			170.6E	25													
96110912			170.7E	25													
96110918			170.6E										_				
96111000			170.7E														
96111006			171.0E														
96111012			171.9E	30													
96111018			173.1E	30													
96111100			174.4E	30													
96111106			175.8E	25													
96111112			177.3E	25													
96111118			178.BE	25													
96111200		22.2N	179.1W	25													
			AUCDA	C.D.	20	0.6	172	175									

AVERAGE 29 86 173 175 # CASES

TROPICAL DEPRESSION 39W

	WRN	BEST	TRAC	:K		PO	SITIC	N ERRO	ORS	,		v	IND	ERRO	RS	
DTG	NO.	LAT I	LONG	WIND (KT)	00	12	24	36	48	72	00	12	24	36	48	72
96110612		13.8N 12	5.4E	15												
96110618		14.5N 12	5.4E	20												
96110700		15.2N 12	5.2E	20												
96110706		15.8N 12	4.8E	25												
96110712		16.3N 12	4.3E	25												
96110718		16.8N 12	23.6E	25												
96110800		17.3N 12	22.8E	30												
96110806	. 1	17.8N 12	1.6E	30	47	70	120	162			-5	-5	- 0	5		
96110812		18.1N 12	0.3E	30												
96110818	2	18.7N 11	9.7E	30	48	135	188				-5	-5	-10			
96110900		19.2N 11	9.0E	30												
96110906	3	19.8N 11	8.5E	30	65	135					-5	-5				
96110912		20.4N 11	8.0E	30												
96110918		19.8N 11	7.6E	25												
96111000		19.2N 11	17.9E	25												

AVERAGE 54 114 154 163 # CASES

TROPICAL DEPRESSION 40W

	WRN	В	BEST TRA			PC	SITIC	N ERR	ORS			Ģ	IND	ERRO	RS	
DTG	NO.	LAT	LONG	WIND	00	12	24	36	4 B	72	00	12	24	36	48	72
				(KT)												
96112300		8.0N	151.0E	15												
96112306		8.2N	150.8E	15												
96112312		8.6N	150.4E	15												
96112318		9.2N	149.7E	15												
96112400		10.0N	148.6E	15												-
96112406			147.4E	15												
96112412		11.6N	146.1E	20												
96112418		12.3N	144.8E	20												
96112500	1	13.4N	143.6E	20	30	155	213	251	278	294	0	0	10	20	30	55
96112506	2	14.9N	142.9E	20	87	167	199	225	253	241	0	0	10	20	30	50
96112512	3	16.1N	142.4E	25	86	58	38	29	75	236	-5	0	10	20	35	45
96112518	4	17.0N	141.7E	25	90	90	82	115	167	113	5	10	15	25	40	50
96112600	5	17.5N	141.0E	25	90	145	223	333	428	384	5	10	15	15	10	5
96112606	6	17.8N	140.3E	25	100	136	176	236	296	272	0	5	15	15	5	5
96112612	7	18.1N	139.6E	25	125	171	206	309	354	359	0	5	20	15	5	5
96112618	8	18.3N	139.0E	25	154	203	276	376	397	411	0	5	15	10	5	0
96112700	9	18.3N	138.5E	25	5	42	149	188			0	5	5	0		
96112706			138.1E	25												
96112712	10		137.7E	20	26	111	161				5	0	-10			
96112718			137.0E	20												
96112800			135.9E	20												
96112806			134.5E	25												
96112812			133.2E	25												
96112818		16.0N	132.1E	25												
96112900	11		131.2E	25	181	193	256	339			5	5	5	5		
96112906		15.3N	130.6E	25												
96112912	12		130.4E	25	180	232	306	391			0	0	0	0		
96112918			129.9E	25												
96113000	13	13.7N	129.3E	25	150	201	277				0					
96113006			128.6E	25												
96113012	14		127.8E	25	234	322	440				0	5	0			
96113018			127.0E	25												
96120100	15		126.3E	20	35	164					5					
96120106			126.0E	20												
96120112			125.8E	20												
96120118			125.7E	15												
96120200		8.5N	125.6E	10												
			AVERAG	E	105	160	215	254	281	289						

AVERAGE 105 160 215 254 281 289 # CASES 15 15 14 11 8 8

TROPICAL DEPRESSION 41W

	WRN	BEST TRA	CK		PC	SITIC	N ERR	ORS			W	IND	ERRO)RS	
DTG	NO.	LAT LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72
			(KT)												
96121218		4.2N 103.7I													
96121300		4.2N 104.3I													
96121306		4.2N 104.9E													
96121312		4.2N 105.5													
96121318		4.2N 106.1													
96121400		4.2N 106.6													
96121406	1	4.2N 107.1		119	216	306	391			0	5	0	-5		
96121412		4.1N 107.4													
96121418	2	3.9N 107.7E	25	83	170	26B	394			0.	5	0	-5		
96121500		3.8N 107.9	25												
96121506	3	3.6N 108.2E	25	17	73	91	78			0	5	5	5		
96121512		3.5N 108.4	25												
96121518	4	3.3N 108.7E	25	50	64	33	69			0	5	5	-5		
96121600		3.2N 109.3I	25												
96121606	5	3.3N 109.7E	25	40	69	128	155			0	0	-5	-5		
96121612		3.5N 110.1	25												
96121618	6	4.0N 110.5	25	42	67	80	75			0	-5	-5	-5		
96121700		4.4N 110.3	30												
96121706	7	4.5N 110.1	30	8	8	26	43			0	0	0	5		
96121712		4.6N 109.8	30												
96121718	8	4.6N 109.6	30	43	78	117	153			0	0	5	5		
96121800		4.6N 109.5I	30												
96121806	9	4.6N 109.3I	30	0	13	16	41			0	5	0	. 0		
96121812		4.7N 109.1I	30												
96121818	10	4.8N 109.0	25	0	13	42				0	0	0			
96121900		4.9N 108.8I								-	-	-			
96121906	11	4.9N 108.5I	-	17	60	126	185			0	0	0	5		

AVERAGE 41 79 115 159 # CASES 13 13 12 10

TYPHOON FERN (42W)

	WRN	BEST T	DACK		D.C	19191	N ERF	2000				JTND	ERRO	np q	
DTG	NO.	LAT LONG		00	12	24	36	48	72	00	12	24	36	48	72
2.0		2011	(KT)				30	••				- 1	50		
96121712		5.2N 151.													
96121718		5.4N 150.													
96121800		5.5N 150.													
96121806		5.6N 149.													
96121812		5.7N 148.													
96121818		5.9N 148.													
96121900		6.1N 147.													
96121906		6.3N 146.													
96121912		6.5N 146.													
96121918		6.8N 145.													
96122000		7.4N 144.													
96122006		7.5N 143.													
96122012		7.6N 142.													
96122018		7.8N 142.													
96122100		7.9N 142.													
96122106		8.0N 141.													
96122112		8.2N 141.													
96122118	1	8.3N 141.		101	124	155	175	207	260	-10	-10	5	20	25	20
96122200	2	8.5N 141.		50	69	96	131	173	276	-5	5	25	35	30	25
96122206	3	8.6N 141.		55	61	96	141	180	284	ō	10	25	30	25	20
96122212	4	8.7N 141.0		66	77	97	115	150	240	Ŏ	10	15	10	5	5
96122218	5	8.8N 140.		53	59	85	120	142	192	Ö	5	5	ō	ő	-5
96122300	6	B.BN 140.		21	42	97	122	162	222	Ö	ő		-15		
96122306	7	8.8N 140.4		30	72	118	143	175	208	0			-15		
96122312	B	8.7N 140.1		51	105	118	138	149	176		-10				
96122318	9	8.5N 139.		85	119	137	147	163	166		-15				
96122400	10	8.5N 139.0		78	72	84	101	96	141	-10			-20		
96122406	11	8.6N 138.		13	24	47	64	49	113	-5	-5	ō		-20	
96122412	12	8.8N 138.		17	30	60	80	90	193	ŏ	5	5	ō	-5	-5
96122418	13	9.0N 138.3		- 8	31	76	83	121	246	ō	5	ō	-5	-5	-5
96122500	14	9.2N 138.2		5	47	69	51	104	204	ŏ		-	-15	_	-
96122506	15	9.4N 138.2		11	47	59	55	109	171	_	-10			-15	-20
96122512	16	9.8N 138.3		6	6	23	24	86	98		-10			ō	-5
96122518	17	10.1N 138.4		13	8	37	83	117	68		-10			-15	-20
96122600	18	10.6N 138.		12	18	35	88	99	6	-5		-10	-5	-5	10
96122606	19	11.3N 138.7		5	48	75	107	86	78	ō	-5	5	5	5	30
96122612	20	11.7N 138.8	E 80	11	32	71	86	38	84	-5	5	20	20	10	35
96122618	21	12.0N 138.8		11	39	59	74	87	120	ō	15	25	20	10	40
96122700	22	12.4N 138.	-	24	51	43	49	33	349	ŏ	10	15	10	20	40
96122706	23	13.0N 138.		0	8	34	41	97	493	-5	ō	5	5	25	40
96122712	24	13.6N 138.8		ō	23	26	108	255	687	-5	Ō	-5	5	20	30
96122718	25	14.3N 139.1		ō	31	57	74	193	689	ō	ō	-5	15	25	35
96122800	26	14.8N 139.		21	38	54	178	371	955	Ö	-5	5	25	30	40
96122806	27	15.8N 140.	5E 75	30	42	114	263	475	1102	-5	-10	10	25	30	40
96122812	28	16.2N 141.		24	69	165	313			Ō	10	25	30	35	35
96122818	29	16.8N 142.0	SE 75	29	93	216	408	714		0	20	30	35	40	
96122900	30	17.1N 143.0	6E 60	53	130	260	484	834		10	30	35	40	40	
96122906	31	17.2N 144.0		66	115	195	375	528		10	25	30	40	35	
96122912	32	17.2N 145.	E 40	107	149	211	335	390		15	20	25	25	20	
96122918	33	17.2N 146.2	2E 35	107	129	234	336			15	20	25	20		
96123000	34	17.2N 146.		0	46	173	230			15	15	10	5		
96123006	35	17.2N 147.		11	111	206				5	10	5			
96123012		17.1N 147.2								•		-			
96123018		16.7N 146.													
96123100		16.7N 146.													
96123106		16.9N 146.													
96123112		17.0N 146.													
				• •					200						

AVERAGE 34 62 106 157 219 320 # CASES 35 35 35 34 32 28

TROPICAL STORM GREG (43W)

	WRN	В	EST TRA	CK		PC	SITIC	N ERF	RORS				MIND	ERRO	RS	
DTG	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72
				(KT)												
96122106	•	7.8N	110.0E	15												
96122112		8.0N	110.1E	15												
96122118		8.0N	110.5E	15												
96122200		8.0N	110.7E	15												
96122206		7.9N	110.9E	15												
96122212		7.8N	111.1E	15												
96122218		7.7N	111.3E	15												
96122300		7.6N	111.4E	20												
96122306		7.5N	111.5E	25												
96122312		7.4N	111.6E	25												
96122318		7.3N	111.8E	25												
96122400		7.3N	112.1E	25												
96122406	1	7.3N	112.4E	30	17	64	101	109			0	-10	-15	-15		
96122412		7.2N	112.9E	35											•	
96122418	2	6.9N	113.4E	40	61	107	152	320			-10	-15	-15	0		
96122500	3	6.6N	113.9E	45	0	24	93	239	414		-5	-5	0	-5	-5	
96122506	4	6.5N	114.4E	45	13	49	143	329	474		-5	- 5	5	-5	0	
96122512	5	6.5N	114.9E	45	16	124	329	516			-5	5	5	0		
96122518	6	6.6N	115.8E	45	37	205	425	573			-5	10	5	5		
96122600	7	6.7N	117.3E	35	29	176	303				0	0	5			
96122606	8	5.8N	119.2E	30	48	174	261				0	0	5			
96122612		5.5N	121.3E	30												
96122618	9	4.9N	123.4E	30	29	166					0	10				
96122700		4.1N	125.0E	25												
96122706	10	3.3N	126.1E	20	0						5					•
			AVERAGE		26	121	226	348	444							
			# CAS	ES	10	9	8	6	2							

6.2.2 NORTH INDIAN OCEAN — This section includes verification statistics for each warning in the North Indian Ocean during 1996.

JTWC BEST TRACK, FORECAST TRACK AND INTENSITY ERRORS BY WARNING

TROPICAL CYCLONE 01B

W	RN	BI	EST TR	ACK		P	OSITI	ON ER	RORS				WIND	ERR	ORS	
DTG NO	١.	LAT	LONG	WIND	00	12	24	36	48	72	0.0	12	24	36	48	72
				(KT)												
96050106			91.5E	20												
96050112			91.4E	25												
96050118			91.3E	25												
96050200			91.2E	25												
96050206			91.2E	25												
96050212			91.1E	25												
96050218		10.5N		25												
96050300		11.0N		25												
96050306		11.5N		25												
96050312		12.1N		25												
96050318		12.5N		25												
96050400		12.9N		25												
96050406		13.3N		25												
96050412		13.6N		25												
96050418		13.9N		25												
96050500		14.2N		25												
96050506		14.6N		25												
96050512		14.9N		25												
96050518		15.4N		25												
96050600		15.9N		25												
96050606		16.6N		25												
96050612		17.3N		25												
96050618	_	17.8N		30							_	_	_			
96050700	1	18.3N		30	47	96	198	321			0	0	0	15		
96050706	2	18.8N		30	58	130	254	389			0	-5	5	20		
96050712	3	19.5N	89.9E	35	0	52	113				-5	-5	10			

```
TROPICAL CYCLONE 01B (CONTINUED)
96050718 4 20.4N 90.9E 40
                                    35
                                         68
          5 21.3N 92.1E 40
6 22.2N 93.4E 35
                                                            -5
96050800
                               17
                                    60
96050806
                               25 138
96050812
             23.0N 94.8E 30
96050818
             23.7N 96.2E 25
                   AVERAGE
                               26
                                    86 159 356
                    # CASES
                                     6
TROPICAL CYCLONE 02A
       WRN
                BEST TRACK
                                     POSITION ERRORS
                                                                  WIND ERRORS
 DTG
       NO.
             LAT LONG WIND 00
                                    12 24 36 48
                                                       72
                                                            00 12 24 36 48 72
                         (KT)
96060900
             16.6N 62.7E 15
             16.9N 62.4E 15
96060906
             17.1N 62.0E 15
96060912
             17.3N 61.6E
96060918
96061000
             17.5N 61.1E 25
             17.7N 60.6E 25
96061006
96061012
             17.9N 60.0E 30
96061018
             18.2N 59.3E 35
96061100
          1 18.6N 58.7E 40
                               83 127 173 168
                                                           -10
                                                                5 15
                                                                       20
          2 19.2N 58.0E 40 110 222
3 20.1N 57.6E 35 0 71
96061106
                                                                0 10
                                       271
                                                             0
96061112
                                        151
                                                             0
                                                                 0
                                                                    10
          4 20.7N 57.2E 35
21.0N 56.5E 30
96061118
                                0 182
96061200
96061206
             21.0N 55.9E 20
96061212
             21.0N 55.4E 15
                   AVERAGE
                               49 151 199 169
                   # CASES
                                         3
TROPICAL CYCLONE 03B
       WRN
                BEST TRACK
                                     POSITION ERRORS
                                                                  WIND ERRORS
             LAT LONG WIND 00
                                   12 24 36 48 72 00 12 24 36 48 72
                         (KT)
              8.2N 87.8E 15
96061100
              8.5N 87.7E
96061106
96061112
              8.8N 87.6E
96061118
              9.3N 87.4E
96061200
              9.9N 86.9E
         1 10.4N 86.2E 30
                               42 121 214 265
                                                260
                                                      196
                                                             0 -5
                                                                   0 10 20
96061212
          2 10.9N 85.5E 35
                               0 148
                                        213 212
                                                175
                                                       R1
                                                             0 -10
                                                                   -5
                                                                        0 10
                                                                               20
         3 11.5N 84.6E
96061218
                         40
                               26
                                   97
                                                           -10 -10
                                                                   -5
                                        116
                                             98
                                                  40
                                                       75
                                                                        0 10
                                                                               10
         4 12.2N 83.7E 45
5 12.8N 82.9E 45
96061300
                               31
                                    42
                                        77
                                            179
                                                 317
                                                             n
                                                               10 15 -5 -15
96061306
                               79
                                   37
                                        24
                                             66
                                                 105
                                                                5 -20
                                                                        5 -20
96061312
          6 13.4N 82.3E 45
                               0
                                 86 128
                                            198
                                                 230
                                                               10 15 -5 -15
          7 13.9N 81.9E 45
96061318
                               0 148
                                       258
                                            335
                                                 388
                                                             0 -5 -5 -10 -15
          8 14.1N 81.8E 45
                               0 133 218
                                                             0 0 -10 -20
                                            280
96061406
          9 14.5N 81.8E 45
                                                 141
                                                       74
                               0 118 178
                                            182
                                                             0 0 0 -5 -15 -5
96061412 10 15.1N 82.1E 45
                               82
                                  179
                                       241
                                            267
                                                 245 161
                                                             0 -5 -5 -10 -15
                                                                               -5
96061418 11 15.8N 82.6E 45
                             138 220 266
                                           266
                                                 228
                                                             0 -5 -5 -10 -10
96061500 12 16.4N 83.0E 45
                                   91
                                       110
                                                             0 -20 -25
96061506 13 16.8N 83.3E 45
                                  46
                                        46
                                                  42
                                                               0 -10 -15 -10
96061512 14 17.2N 83.6E 45
                                        67
                              11
                                   13
                                           131
                                                 182
                                                             0
                                                               0 -10 -10 -10
96061518 15 17.5N 83.7E 45
                                   43 110
                                                             0 -5 -5 -5
                               0
                                            182
                                                 207
96061600 16 17.8N 83.7E 45
96061606 17 18.0N 83.5E 45
                              12
                                   65 130
                                                             0 -10 -10 -10
                               51 133
                                       229
                                                            -5 -10 -5
96061612 18 18.2N 83.1E 45
                               61 111 152
                                                               -5
96061618 19
             18.3N 82.7E 40
                              20
                                   18
                                        13
                                                             0
                                                                0
                                                                   -5
96061700 20 18.4N 82.2E 35
                                                             0 -10
                                   45
             18.5N 81.6E
96061706
                         30
96061712
             18.8N 81.2E
```

AVERAGE 28 95 147 192 197 122 CASES 20 20 19 15 13 7

19.3N 81.0E

19.8N 80.9E

20.4N 80.8E 25

21.3N 80.7E 25

22.1N 80.7E 25

25

96061718 96061800

96061806 96061812

TROPICAL CYCLONE 04A

WRN BEST TRACK				POSITION ERRORS					WIND ERRORS							
	NO.	LAT	LONG	WIND	00	12	24	36	48	72	00	12	24	36	48	72
D10 .		DA.	Dong	(KT)	•	12		30	40		•	•-			•••	-
06061600		16 64	72.0E													
96061500				15												
96061506			72.0E	15												
96061512			71.9E	15												
96061518			71.8E	15												
96061600			71.7E	25												
96061606		17.2N	71.4E	20												
96061612		17.4N	71.0E	20												
96061618		17.5N	70.5E	25												
96061700		17.5N	69.6E	25												
96061706		17.6N	69.1E	25												
96061712		18.1N	69.1E	30												
96061718	1	18.4N	69.5E	35	0	97	179	267	371	507	0	-5	-20	-5	20	30
96061800	2		69.9E	40	48	128	194	290	366	439	-5	-15		5	25	35
96061806	3		70.3E	45	18	50	105	139	137	42		-20	-5	15	10	5
96061812	4		70.6E	55	21	34	84	97	45			-15	ō	5	5	7.
96061818	5		70.8E	65	12	16	29	43	-10			-15	Ö	ō	٠	
96061900	6		70.8E	60	23	60	77	97				-10	Ö	ŏ		
	7		70.9E	55	55	118	163	186			-10	-10	-5	Ö		
96061906											-10	v	,-3	U		
96061912	8		71.4E	45	42	61	71	134			U					
96061918			71.7E	35												
96062000			72.0E	30												
96062006			72.2E	30												
96062012		25.6N	72.4E	25												
96062018		26.0N	72.6E	25												
96062100		26.3N	72.9E	25			•									
96062106		26.6N	73.2E	25												
96062112		26.9N	73.5E	25												
96062118		27.1N	73.8E	25												
96062200		27.3N	74.1E	25												
96062206			74.4E	25												
96062212			74.8E	25												
96062218			75.1E	25												
96062300			75.4E	20												
96062306			75.8E	20												
96062312			76.1E	20												
96062318			76.1E	20												
96062400			76.7E	20												
96062406			77.0E	20												
96062412			77.3E	15												
96062418			77.7E	15												
96062500			78.1E	15												
96062506			78.6E	15												
96062512		29.7N	79.2E	15												
			AVERA	GE	28	71	113	157	230	330						
			4 030							•						

TROPICAL CYCLONE 05A

	WRN	BE	ST TRA	CK		POS	SITION	ERR	ORS			H	IND	ERRO	RS	
DTG	NO.	LAT	LONG	WIND (KT)	00	12	24	36	48	72	00	12	24	36	48	72
61014	00	9.1N	91.7E	15												
61014	06	9.5N	90.5E	15												
61014	12	10.0N	89.2E	15												
61014	18	10.6N	87.9E	15												
61015	00	11.3N	86.6E	15												
61015	06	11.9N	85.4E	15												
61015	12	12.4N	84.4E	15												
61015	18	12.9N	83.7E	15												
61016	00	13.3N	83.2E	15												
61016	06	13.4N	82.7E	20												
61016	12	13.4N	82.3E	20												
61016	18	13.3N	82.0E	20												
61017	00	13.1N	81.7E	20												
61017	06	12.9N	81.3E	20												
61017	12	12.8N	80.8E	20												
61017	18	12.9N	80.4E	20												
61018	00	13.0N	80.1E	15												
61018	06	13.0N	79.8E	15												
61018			79.5E													
61018			78.8E													
61019			78.1E													

```
TROPICAL CYCLONE 05A (CONTINUED)
              13.0N 77.5E 15
96101906
96101912
              13.0N 76.9E 15
96101918
              13.0N 76.3E 15
              13.1N 75.4E
96102000
96102006
              13.2N 74.4E
                           15
              13.2N 73.2E
96102012
96102018
              13.2N 72.1E
                           20
96102100
              13.3N 71.3E
                           20
96102106
              13.5N 70.7E
96102112
              13.7N 70.3E
96102118
              13.8N 70.0E
96102200
              13.9N 69.8E
                           30
96102206
              14.0N 69.7E
           1 14.2N 69.6E
                                         143 201 249 280
                                                              -5 -15 -20 -20 -10
96102212
                                     82
                           40
                                34
96102218
           2 14.3N 69.7E
                           45
                                13
                                     58
                                         139
                                               204
                                                    255
                                                         248
                                                              -10 -20 -25 -15 -10 10
96102300
           3 14.5N 69.9E
                                31
                                      95
                                          175
                                               236
                                                    268
                                                         243
                                                              -10 -20 -15 -10
96102306
              15.0N 70.1E
                                    138
                                          200
                                               250
                                                                        0
                           55
                                58
                                                    260
                                                         240
                                                               -5 -10
                                                                           -5
              15.8N 70.2E
96102312
                                21
                                          150
                                               180
                                                    156
                                                          34
                                                                           10
                                                                               15
                           60
                                      90
              16.8N 70.2E
96102318
                           65
                                12
                                      51
                                          77
                                               140
                                                    238
                                                         417
                                                              -10
                                                                           10
                                                                               15 10
              17.6N 70.0E
96102400
                                34
                                      71
                                         124
                                                    280
                                                               -5
                                                                        n
                                                                                0 -10
                           60
                                               182
                                                         472
                                                                    5
                                                                            0
96102406
           8 18.3N 69.9E
                           55
                                 8
                                      43
                                           50
                                                37
                                                     73
                                                         147
                                                                    5
                                                                        5
                                                                          10 10 -10
96102412
           q
              19.0N 69.9E
                           55
                                30
                                      47
                                           49
                                                51
                                                     96
                                                         144
                                                                -5
                                                                    0
                                                                       10
                                                                           10 10 -20
96102418
         10
              19.5N 70.0E
                                37
                                      49
                                           51
                                                90
                                                    133
                                                         191
                                                                    5
                                                                       15
                                                                           15
                                                                               5 -15
96102500
          11
              19.8N 70.1E
                           50
                                20
                                      53
                                          131
                                               220
                                                    305
                                                         436
                                                                   10
                                                                       10
                                                                           10 -5 -10
96102506 12
              20.0N 70.1E
                           45
                                37
                                         168
                                               257
                                                    345
                                                                    5
                                                                       10
                                                                            0 -15
96102512 13
              20.1N 69.9E
                                32
                                      77
                                                                0
                                                                   10
                           40
                                         126
                                               194
                                                                       10
                                                                           -5
              20.0N 69.7E
9610251B 14
                                 45
                                      72
                           35
                                                                0
                                                                   10
                                         117
                                                                       -5
96102600 15 19.8N 69.7E
                           30
                                      41
                                                                    0
96102606
              19.6N 69.7E
                           25
96102612
              19.4N 69.7E
96102618
              19.0N 69.6E
96102700
              18.4N 69.3E
              17.8N 69.0E
96102706
96102712
              17.0N 68.6E
                           45
              16.2N 68.1E
96102718
                           40
96102800 16 15.5N 67.5E
                           35
                                      41
                                           21
                                                41
96102806 17 15.0N 67.0E
                           35
                                34
                                      45
                                           80
                                              121
                                                    172
                                                                            Ω
                                                                               -5
96102812 18
              14.8N 66.6E
                           35
                                 5
                                     18
                                           58
                                               96
                                                    138
                                                         172
                                                                0
                                                                            0
                                                                               -5
                                                                                    -5
96102818 19
              14.5N 66.0E 35
                                32
                                     58
                                         111
                                              156
                                                    184
96102900 20
             14.3N 65.1E
                                68
                                    140
                                               247
                           35
                                         184
                                                    266
96102906 21 14.1N 64.1E
                                                                       -5
                           35
                                49
                                    102
                                         139
                                               160
                                                    162
                                                                0
                                                                    0
                                                                       -5
96102912 22
             13.9N 62.8E
                                33
                                     33
                                                                0
                                                                   -5
                                                                           -5
                           35
                                          29
                                                18
                                                     75
                                                                               -5
96102918 23 13.7N 61.6E 35
                                41
                                      31
                                          11
                                                18
                                                     63
                                                                0
                                                                   -5
                                                                      -10
                                                                               -5
96103000 24 13.7N 60.6E 35
96103006 25 13.7N 59.4E 35
                                29
                                               119
                                      52
                                         103
                                                    106
                                                                n
                                                                    0
                                                                        0
                                34
                                      60
                                          88
                                               103
                                                    116
                                                                0
                                                                    0
                                                                        0
96103012 26 13.7N 58.3E
                                 0
                                      40
                                           70
                                                87
                                                                0
                                                                    0
96103018
          27
              13.6N 57.6E
                                      64
                                           7 B
                                                                    0
                                                93
96103100 28 13.5N 56.7E 30
                                36
                                      76
                                         100
                                                                    0
96103106 29
              13.3N 56.1E
                           30
                                33
                                     88
                                                                0
                                         167
                                                                        0
96103112
         30 13.0N 55.4E
                           30
              12.3N 54.8E 25
96103118
              11.8N 54.3E 25
96110100
96110106
              10.9N 53.8E 25
96110112
              10.1N 53.3E 25
96110118
               9.3N 52.8E 25
96110200
               8.5N 52.4E
96110206
               7.7N 51.9E 20
                    AVERAGE
                                33
                                      68
                                         105 141
                                                   182
                    # CASES
                                30
                                      30
                                          28
                                               25
                                                     22
TROPICAL CYCLONE 06B
                 BEST TRACK
                                      POSITION ERRORS
                                                                     WIND ERRORS
        WRN
DTG
              LAT LONG WIND
                               00
                                                          72
                                                               00 12 24 36 48 72
        NO.
                                     12
                                          24
                                               36
                                                     48
                           (KT)
0696102118
            91N 932E 20
96102200
               9.5N 93.1E
96102206
               9.9N 93.0E 25
96102212
              10.2N 92.9E
                           25
              10.5N 92.8E 25
96102218
```

10.7N 92.6E 25

11.0N 90.9E 25

11.4N 89.3E 25

10.9N 92.2E 25 10.9N 91.7E 25

11.2N 90.0E

```
TROPICAL CYCLONE 06B (CONTINUED)
              11.6N 88.7E 25
96102412
96102418
              11.8N 88.2E
96102500
              12.0N 87.8E
96102506
              12.2N 87.4E
                           30
                                26
                                     58
                                          81 128 155 230
                                                                0
                                                                   0 5 10 15 -10
96102512
              12.4N 87.0E
                                71 129
                                         155 186
                                                                   0 0 10
                                                                               0 -10
                                                  235
                                                                   5 -10 -20
96102518
              12.6N 86.6E
                           35
                               175
                                    290
                                         393
                                              483
                                                                D
96102600
              12.9N 86.2E
                               152
                                    205
                                         281
                                              367
                                                   491
                                                                   0 -10 -15 -20
                           3.5
                                                   501
                                                                   0 -10 -15 -20
96102606
              13.2N 85.7E
                               170
                                         285
                           40
                                    221
                                              378
96102612
              13.6N 85.4E
                           45
                                56
                                     5.8
                                         103
                                              203
                                                   343
                                                               0
                                                                   5 10 15
                                                                              -5
96102618
              14.2N 85.3E
                           45
                                64
                                     62
                                         126
                                              235
                                                   371
                                                                   5 10 15
                                                                               Λ
96102700
           8
              14.7N 85.3E
                                13
                                     58
                                         142
                                              244
                                                   367
                                                                0
                                                                      15
                                                                          20
                                                                              25
                           45
              15.5N 85.4E
                                21
                                     75
                                                                      10
                                                                          20
                                                                               30
96102706
                                         167
                                              291
                                     87
                                                                0
                                                                           25
96102712
         10
              16.2N 85.7E
                           45
                                33
                                         189
                                              326
                                                                      10
96102718
              17.0N 86.2E
                                52
                                    112
                                         221
                                                                      15
         11
                           45
              18.0N 86.8E
                                                                0
96102800
         12
                           45
                                58
                                    158
                                         309
                                                                      25
96102806
         13
              19.1N 87.5E
                                82
                                    188
                                                                0
                                                                   5
                                                                      20
                           45
                                         346
96102812
         14
              20.4N 88.2E
                           45
                                Q 5
                                    188
                                                                n
                                                                  15
96102818
         15
              21.9N 88.9E
                           40
                                23
                                     76
                                                                5
                                                                  15
96102900 16
              23.7N 89.6E 30
96102906
              14.1N 64.1E
                    AVERAGE
                                72 132 216 293 364 312
                    # CASES
                                16
                                     15
                                          13
                                              11
                                                     Я
TROPICAL CYCLONE 07B
                                     POSITION ERRORS
                                                                   WIND ERRORS
                BEST TRACK
                                                         72
              LAT LONG WIND 00
                                     12 24 36 48
                                                              00 12 24 36 48 72
       NO.
                          (KT)
96110100
              15.0N 97.3E
                           15
96110106
              15.7N 96.5E
                           15
96110112
              15.9N 96.0E
                           15
96110118
              16.2N 95.2E
96110200
              16.4N 94.3E
                           15
              16.4N 93.5E
96110206
                           15
              16.4N 92.9E
96110212
                           15
              16.2N 92.1E
96110218
                           15
96110300
              16.1N 91.4E
                           20
96110306
              16.0N 90.8E
                           20
96110312
             16.0N 90.2E
                                     30
                                          62 108 142
                                                        116
                                                                  0 -5 -20 -25 -80
96110318
          2
              16.0N 89.5E
                                33
                                          37
                                               62
                                                    93
                                                         93
                                                               0 -5 -15 -25 -35 -80
                           25
                                     30
             16.0N 88.8E 30
                                                                 -5 -20 -30 -50 -60
96110400
                                               60
                                                   104
96110406
             16.0N 88.3E
                           35
                                11
                                     29
                                          49
                                               73
                                                   128
                                                        181
                                                               0 -5 -10 -20 -80 -30
96110412
             16.1N 87.7E
                                                    67
                                                              -5 -15 -20 -35 -80 -10
                                 0
                                     18
                                          32
                                                         26
                           40
                                               62
96110418
             16.0N 87.0E
                                                              -5 -15 -30 -50 -80
                           50
                                13
                                     21
                                          24
                                               13
                                                    33
                                                         83
             16.0N 86.3E
          7
                                                              -5 -10 -25 -50 -45
96110500
                           60
                                23
                                     26
                                          13
                                               24
                                                    54
96110506
          R
             16.0N 85.6E
                           65
                                 5
                                     12
                                          49
                                               97
                                                  120
                                                               0 -10 -40 -50 -20
96110512
          9
             16.0N 84.9E
                           75
                                 0
                                     11
                                          50
                                               90
                                                   101
                                                             -10 -30 -40 -20
96110518
             16.0N 84.1E 85
                                                              -10 -30 -40
                                     16
                                          62
                                               96
96110600
         11
              16.0N 83.6E 100
                                18
                                     67
                                         104
                                                              -30 -45 -35
                                              118
                                                                           -5
96110606
              16.2N 82.9E 115
         12
                                11
                                     30
                                          74
                                                               0 10 15
                                                                          10
                                               85
96110612
         13
              16.5N 82.4E 120
                                13
                                     33
                                          62
                                                              -5
                                                                 20 35
96110618
              16.8N 81.7E 115
         14
                                12
                                     82
                                         132
                                                               5
                                                                 50
                                                                      45
              17.3N 80.8E 80
96110700
         15
                                 0
                                     33
                                                              10 25
96110706
         16
             17.5N 79.6E 50
                                11
                                     58
                                                              30
                                                                  35
96110712
              17.6N 78.8E 30
96110718
              17.8N 77.7E 20
                     AVERAGE
                                 12
                                      32
                                           56
                                                75
                                                     94
                                                        105
                     # CASES
                                      16
                                 16
                                           14
                                                12
TROPICAL CYCLONE 08B
                 BEST TRACK
                                      POSITION ERRORS
                                                                    WIND ERRORS
        NO.
              LAT LONG WIND
                               00
                                     12 24 36 48
                                                         72
                                                             00 12 24 36 48 72
                          (KT)
96112612
               8.9N 92.3E 20
96112618
               9.2N 91.3E
96112700
               9.4N 90.3E
96112706
               9.6N 89.2E
96112712
              10.0N 87.9E
              10.4N 86.8E
96112718
                           25
              11.1N 85.9E
96112800
                           30
             11.7N 85.3E
                                         129
                                                   431
                                                        593
                                                              -5 -5
                                                                           0 -5 -25
96112806
                           35
                                     64
                                             258
                                                              -5 -10
                                                                           0 -15 -25
96112812
          2 12.4N 84.9E 35
                                16
                                     29
                                        107 280
                                                   46B
                                                        595
                                                                     -5
```

3 13.0N 84.6E

4 13.6N 84.4E 45

0 29 151

-5 -5

0 -15 -20

```
TROPICAL CYCLONE 08B (CONTINUED)
                              29 141 319
                                           473 522
                                                            0
                                                               5
                                                                   5 -5 -15 -15
96112906
          5 14.1N 84.4E 45
                                                     563
                                                                  0 -5 -15 -15
             14.6N 84.8E
                                                     511
96112912
                              70 233
                                       397
                                            462
                                                457
                                                            n
                                                                5
                          45
                                                               0 0 -5 -5 -5
                                                            ٥
96112918
          7
             15.0N 85.7E 45
                             104 233
                                      322 325
                                                358
                                                     602
                                                              -5 -5 -5 -5 -30
96113000
          8
             15.3N 86.9E 45
                              88
                                 170
                                      267
                                            386
                                                535
                                                     875
                                                            n
96113006
             15.3N 87.9E 50
                              50
                                 119
                                       252 370
                                                487
                                                     694
                                                           -5 -10 -10 -5 -5 -35
             15.1N 88.8E
                              49
                                  159
                                       300
                                            436
                                                578
                                                     780
                                                            0
                                                               0 -10 -10 -10 -40
96113012
         10
                         55
             14.7N 89.2E 55
                              72
96113018
                                  163
                                       258
                                           355
                                                464
                                                     666
         11
                                                                   5 10 0 0
             14.3N 89.0E 55
                              62
                                       255
                                            323
                                               357
                                                     382
                                                            0
                                                               0
96120100 12
                                  162
                                                                  0 -5 -15 -20
             14.0N 88.6E
                              13
                                   18
                                       37
                                            54
                                                 79
                                                     109
                                                            0
                                                               0
96120106 13
                         55
                                            87 133
                                                               0 0 -10 -20 -50
96120112 14
             13.9N 88.1E 55
                              13
                                   33
                                        66
                                                     253
                                                            Λ
                                                               0 -5 -20 -15 -50
96120118
        15
             13.9N 87.6E
                         50
                              13
                                   24
                                        37
                                            66
                                                130
                                                     214
                                                            0
96120200 16
             13.9N 87.1E 50
                              13
                                   30
                                      56 116
                                               154
                                                     242
                                                            0 5 -10 -15 -15 -50
             13.9N 86.6E 45
                                        52
                                            99.
                                                            0 -5 -20 -15 -25 -40
96120206 17
                               0
                                   11
                                                163
                                                     293
96120212 18
             13.9N 86.1E
                               0
                                   13
                                       18
                                            46
                                                105
                                                     272
                                                            0 -10 -20 -15 -40 -40
                         45
                                            94
                                                           -5 -15 -10 -20 -40 -35
             14.0N 85.5E
                         50
                              11
                                   16
                                        34
                                                     276
96120218 19
                                                161
                                   76 136 210
                                                            0 0 10 -25 -40 -30
96120300 20
             14.1N 84.9E
                         55
                              39
                                               295
                                                     366
                                                            0 10 5 5 -20 -20
0 10 -5 -15 -20 -15
                                      73 137
96120306 21
             14.2N 84.3E 60
                              11
                                   26
                                               213
                                                     334
96120312 22
             14.2N 83.8E
                         60
                               5
                                   34
                                       87 153
                                                220
                                                     365
             14.3N 83.3E 55
                                   24
                                       62 113
                                                185
                                                            0 -10 -15 -10 -15
96120318 23
                                                     358
96120400 24
             14.4N 82.9E
                         55
                              26
                                   65
                                      122 175
                                                252
                                                     375
                                                            0 -15 -10 -15 -20
                                                           0 -5 0 -10 -15
-5 0 -10 -15 -15
             14.5N 82.6E 65
                              46
                                   94
                                      156 222 283
96120406 25
                                                     344
                              52 104
                                      171 238
162 212
96120412 26
             14.5N 82.3E 75
                                                296
                                                     325
                                                                             10
             14.5N 82.2E
                         75
                              73
                                                274
                                                            0 10 -5 -10
                                                                         -5
96120418 27
                                 122
                                                            0 5 -10 -10
96120500 28
             14.5N 82.0E 75
                              54 105 149 221 270
                                                                          -5
96120506 29
             14.4N 81.8E
                         65
                               8
                                   30
                                       56
                                           103
                                                117
                                                          -10 -5 -5
                                                                      0
96120512 30
             14.2N 81.5E 60
                                   34
                                        42
                                            50
                                                           -5 -10 -10
                                                            0
96120518 31
             14.0N 81.3E 55
                              23
                                   36
                                        60
                                            109
                                                              -5
                                                                   0
                                                                       5
             13.8N 81.1E 55
                                        94
                                                            0
                                                               0
                                                                  5
                                                                      10
96120600 32
                               Я
                                   26
                                            20 B
                                                              10 15
                                                            O
             13.5N 80.8E 50
                                   42 141
96120606 33
                               5
96120612 34
             13.0N 80.5E 45
                              23
                                   89
                                       173
                                                            O
                                                                5
                                                                   5
96120618 35
             12.5N 79.8E 35
                              18
                                 107
                                                            O
                                                                5
96120700
             12.2N 78.8E 30
96120706
             12.1N 77.5E 20
             11.9N 76.3E 15
96120712
                   AVERAGE
                                   78 147 223 310
```

CASES

7. TROPICAL CYCLONE (TC) SUPPORT SUMMARY

7.1 COMBINED SSM/I- AND IR-DERIVED RAINRATES FOR THE TROPICS

J.F. Turk and J.D. Hawkins Naval Research Laboratory Monterey, CA 93943

Infrared (IR) derived rainrate techniques focus on the cloud-top temperatures to infer rain. These IR techniques typically associate colder cloud tops with higher rainrates. However, there are a number of incorrect assumptions associated with this underlying methodology and a number of alternative explanations have been proposed. The method proposed here takes advantage of the superior rainrate measuring capabilities of the DMSP SSM/I sensor and combines it with the advantages of the frequent updates of infrared geostationary imagery and the associated wide synoptic coverage of geostationary imagery.

The technique basically merges the SSM/I imagery and the IR geostationary imagery by a histogram type matching program after collocating geostationary data that has been mapped to the SSM/I type resolutions (in this case 28 km). The rainrates from the SSM/I are matched with the brightness temperatures from the IR imagery when the SSM/I data are available. A data base is created that serves as a reference table for converting IR temperatures to rainrates over a much larger domain than the swath width of the SSM/I pass.

The technique improves when the number of matches between the SSM/I rainrates and the brightness temperatures from the IR imagery in the reference data base is large. The results have been enhanced recently by the fact there are now four (4) operational SSM/Is available. Thus, for each IR image, the method is applied and a rainrate product is created. The resulting image of rainrates can be used for several purposes: a) a snapshot of current rain over a large domain; b) as input to numerical models using the reverse physical initialization technique; and c) to accumulate the rain over time to give a time series of rainrates for a given TC.

The snapshot rainrate picture and a time series animation of the individual images are very informative about the rain in and around a TC. The rainbands and their evolution are the main features displayed. This helps to augment the SSM/I 85-GHz imagery that is the focus of a study on TC structure and intensity. Preliminary results incorporating these rainrates into NOGAPS via physical initialization (Gregg Rohaly) are very promising and are currently undergoing tests.

Accumulation images are enlightening due to the fact that the images readily depict the diurnal maximums associated with the IR signature of TCs. This type of data may help determine which TCs are wet versus dry and alert forecasters to those TCs that can be particularly troublesome from the standpoint of flooding when they reach landfall. Verification studies are ongoing with P-3 airborne radar data in the Atlantic Ocean and with limited NEXRAD sites in the Northwest Pacific Ocean.

7.2 THE AUTOMATED TC FORECAST-ING SYSTEM

C.R. Sampson and A.J. Schrader
Marine Meteorology Division
Naval Research Laboratory, Monterey CA

The Automated Tropical Cyclone Forecasting (ATCF) System, developed by NRL Monterey, is a computer based application designed to automate and optimize the forecasting process at operational Navy TC warning centers. ATCF was initially installed on PC DOS-based computers at the JTWC in 1988. ATCF version 3.1, installed at JTWC during 1997, is UNIX-based with an X-Windows interface similar to what is seen in Windows 95 applications. This X-Windows interface has markedly simplified navigation through the system, thereby reducing the time required to generate forecasts. Another significant improvement is that ATCF now allows users to track and forecast many storms concurrently. ATCF continues to attract a great deal of interest and has upgrades scheduled for the next few years. Major highlights for these upgrades include integration of satellite derived products such as cloud and water vapor tracked winds, and a redesign of the tropical cyclone database to allow 120-hour track forecasts and wind radii quadrants.

7.3 GEOPHYSICAL FLUID DYNAMICS-NAVY (GFDN) TC MODEL

M.A. Rennick FNMOC Monterey, CA 93943

In May, 1996, FNMOC started running the Navy implementation of the Geophysical Fluid Dynamics Laboratory (GFDL) TC model, GFDN, in support of JTWC. The GFDN is a triple-nested movable mesh model, including initialization, forecast, and diagnostic sections. Some key features include: three computational nests with resolution 1°, 1/3°, and 1/6°, convective adjustment, surface fluxes, second order turbulence, infrared and solar radiation, a bulk subsurface layer, and parameterization of surface features by vegetation type.

The model is initialized from the NOGAPS analysis and the TCBOGUS message issued by JTWC. The TC component is removed from the global analysis, and

replaced by a synthetic vortex generated by an axi-symmetric version of the forecast model constrained by the structure indicated by the TCBOGUS message. An asymmetric (beta-advection) component is also added to the synthetic vortex. Boundary conditions are updated periodically from NOGAPS forecast fields.

FNMOC ran GFDN on the off time (06/18Z) watches whenever a TCBOGUS for a western Pacific TC was received. The model applied the highest priority off time TCBOGUS to the off time NOGAPS analyses (available ~ 1015/2215Z) and used the forecast fields from the previous real time (00/12Z) NOGAPS for boundary conditions. These forecasts were available to JTWC by about 1130/2330Z, in time for their subsequent 12/00Z warnings. Beginning 11 September 1996, if JTWC issued more than one western North Pacific TCBOGUS, the second priority message was applied to the preliminary NOGAPS off time analysis (available $\sim 0745/1945Z$). These forecasts were available by about 0845/2045Z.

The GFDN provided high quality tropical cyclone track guidance in the western Pacific basin. It had excellent detection capability, especially for cyclones of tropical storm intensity or greater. Mean track error decreased with cyclone intensity, while the forecast intensity error increased. Due to its perceived positive impact on the official forecasts, FNMOC now runs GFDN in all basins within JTWC's area of responsibility.

7.4 SSM/I-DERIVED TC STRUCTURE

J.D. Hawkins, J.C. Sandidge, D.A. May, R.J. Holyer, and M.J. Helveston Naval Research Laboratory Monterey, CA 93943

Monitoring TC structure, structure change and intensity via visible and infrared

imagery is inherently limited due to upperlevel cloud obscuration and the subjective nature of the current Dvorak rules for low-end systems before an eye takes shape. Thus, the satellite analyst has a difficult task of accurately determining the TC structure, structure changes and the associated intensity. This statement is even more true at night, when visible data is not available to assist the analyst and coarse resolution infrared (IR) data is the only consistent data set for utilization.

The Special Sensor Microwave/Imager (SSM/I) is a passive microwave imager onboard the Defense Meteorological Satellite Program (DMSP) platforms. The frequencies utilized by the SSM/I have the ability to penetrate many upper-level clouds allowing for a clearer view of the mid- and lower-level structure within a TC. This is crucial to removing one of the main barriers for effective use of visible/IR imagery. The 85-GHz channel on the SSM/I is of particular interest since the spatial resolution is still fair (12-15 km) and is oversampled, meaning the inherent resolution is superior to 15 km.

The Naval Research Lab in Monterey, California (NRL-MRY) has taken advantage of the 85-GHz channel and the associated sampling pattern by adopting a mapping routine developed by Gene Poe at NRL-DC. This mapping routine can accurately map 85-GHz data at resolutions as fine as 1-2 km. In addition, the mapping routine allows the user to map the SSM/I data to the same resolution as coincident visible/IR data from the Operational Linescan System (OLS) on the DMSP or the corresponding geostationary data at nadir. Our studies reveal the remapped 85-GHz data agrees remarkably well with the features one can analyze in the visible/IR data, when clear cut items are in view (e.g., mesoscale convective clusters, eye, eyewall, and rainbands).

The 85-GHz imagery is able to map the rainbands, eyewall and eye very well since

it responds to scattering due to both raindrops and ice particles by virtue of dramatically lowered brightness temperatures. Thus, although cirrus type clouds will preclude an analyst from seeing many or all spiral banding features of interest, the 85-GHz data can clearly depict these dominant items that are necessary for understanding the TC's structure and their changes over time. Time histories of 85-GHz data for a given TC clearly map the evolution of the rainbands, eyewall and eye as the storm develops, matures and then decays.

Of particular interest is the ability to map eyewall cycles. These cycles manifest themselves when the original eye becomes very small and intense. The TC forms a secondary eyewall further out, the circulation supporting the inner eye is cut off and the inner eye collapses. The outer eye then takes over and gradually shrinks in diameter as the storm regains its original structure. Intensity changes are linked to this internal process.

Since the SSM/I can map the TC structure so well, we have developed an automated technique to analyze the 85-GHz imagery and output an estimated TC maximum sustained wind speed. This has been done via a neural network approach where the SSM/I images are represented by Empirical Orthogonal Functions (EOF). Thus, the patterns (e.g., rainbands, eyewall) in the 85-GHz images are contained within the EOFs.

Considerable effort has been expended to create a data base of 85-GHz images of TCs of varying intensity in order to train and validate the neural net. The current data base has over 500 high quality SSM/I images, with which the neural net has used ~ 450 for training and ~ 50 for validation. Earlier efforts suffered from a small data base and limited EOFs that could be used before the neural net encountered memorization problems. In addition, earlier studies revealed that typical RMS errors were > 20 kt when no a priori information was used.

Numerous methods were studied using a priori data in the form of best track intensities (6 or 12 hours before SSM/I image) or the warning intensity at the time of the image. Results improved dramatically as one might expect and RMS errors were 4 and 7 kt respectively.

The latest neural net runs using the expanded 500-set data base now indicate that we can get below the 20-kt RMS error with no a priori knowledge. These results likely indicate that we are approaching the statistical accuracy of the western Pacific best track intensity data base since it is largely based on Dvorak values. We estimate that the limit using this data base is ~ 15 kt.

Work is ongoing to focus on those Atlantic TCs with aircraft reconnaissance and the limited Pacific cases that have high confidence due to additional observations (e.g., islands, ships) being available. These data sets are now being updated in a semi-automated manner during the 1997 season. The SSM/I data are now finding more use for intensity and location related efforts as the capabilities of the 85-GHz data are becoming better understood.

7.5 OPERATIONAL USE OF SCATTEROMETER DATA FOR TCs

J.D. Hawkins, W.L. Jones, L. Rice, and M.J.

Helveston

Naval Research Laboratory

Monterey, CA 93943

and

R.T. Edson

Joint Typhoon Warning Center, Guam

Scatterometer surface wind vectors from both ERS-2 and more recently from the NASA Scatterometer (NSCAT) are utilized by JTWC for mapping the ocean surface wind field in and around tropical cyclones (TCs) in a quasi-real-time mode. Scatterometer data

continued to show good potential for identifying the early potential of developing TCs and gave JTWC an initial estimate of minimum intensity observed within the system. While both ERS-2 and NSCAT are active sensors, NSCAT offered some potentially superior capabilities due to its inherently better resolution of 25 km versus 50 km for ERS-2 and its two 600-km swaths, instead of the single 500-km swath for the ERS satellites. (Unfortunately the satellite carrying the NSCAT sensor stopped transmitting 30 June 1997).

The double swath coverage afforded daily and sometimes twice daily coverage for all TCs, versus the occasional hit with ERS. Thus, the potential to use the data had grown considerably. During the evaluation, questions related to the frequency differences between the two sensors and how the wind directions are derived were investigated.

NSCAT operated at ~ 15 GHz instead of ~ 5 GHz for ERS and thus was susceptible to heavy rain. Under light wind conditions, heavy rain produced anomalously high wind retrievals; while under strong winds, heavy rain caused lighter than normal winds to be produced. Thus, the user needed to know when rain contamination was occurring. NRL-MRY is continuing to investigate several methods to resolve this issue using both SSM/I and geostationary IR data sets for future NSCAT launches.

The SSM/I produces rainrates over its 1400-km swath that are physically based and have undergone extensive validation in the Precipitation Intercomparison Projects (PIP) efforts. It should be noted several of these cases also included TC-type conditions. However, one rarely gets a reasonable matchup with SSM/I overpasses and NSCAT data. Thus, we have produced a rainfall method that incorporates both SSM/I data and the more frequent geostationary IR data.

Through this method we will be able to identify NSCAT values that are contaminated by rainfall, and then to accurately specify the contamination over each NSCAT cell so as to apply a rainrate correction factor for each wind value.

Selecting wind directions for scatterometers is also difficult, since the current retrieval algorithms produce 2-4 possible vectors. Various methods exist to dealias, or select, one wind direction. This usually involves the first guess from a global model, which is a problem, since most global models do not have the resolution needed to resolve the inner circulation of a TC. A number of techniques are under study to determine how best to dealias the NSCAT data with as little dependence from models as possible.

7.6 CONTINUED STUDY OF WIND DISTRIBUTION FORECAST CAPABILITIES AT JTWC

C. P. Guard
ONR-sponsored Research at University of
Guam
Mangilao, Guam 96923

While US and international TC warning centers have performed forecast verifications for decades, the verifications have primarily been limited to the forecast position and intensity. There has been a reluctance todate by the warning centers to validate the predicted distribution of the over-water gale-, storm-, and hurricane-force near-surface winds. This reluctance has resulted in little formal documentation of the extent of the ability of the centers to forecast the surface wind distribution. A study was initiated in 1995 to ascertain the characteristics of JTWC TC wind distribution forecasts. The study was continued in 1996, and in addition, a preliminary evaluation of the wind distribution output of the GFDN model. The research has revealed several interesting and important characteristics of the wind distribution forecasts.

The operational warning time wind distribution was found to be of insufficient quality to use as the verification source. This required a comprehensive reanalysis of the actual wind field data in order to develop a validation data base. Several sources of data were used, and the analyses were checked both for spatial and temporal consistency. JTWC hand-plotted surface-gradient composite analyses, sectional charts, hand-plotted time sections, and raw data messages were the primary sources of conventional data. Also, Doppler radar, scatterometer, and microwave imager remote-sensing data were used.

A statistical breakdown of the data sources used to verify the 35- and 50-kt (17and 26-m/sec) wind revealed that the most common data source for verification of 35-kt winds (17-m/sec) was ship data and for 50-kt (26-m/sec) winds was land observations. In 1995, ERS-1 scatterometer data were evaluated as a validation source and was found to be very good. As a result, scatterometer became a major source of over-water validation data. To put the wind distribution errors in perspective with the total forecast, wind distribution errors were compared with the average annual JTWC track forecast errors for the various forecast periods. The 1996, results were similar to the 1995 results. Major findings are summarized below:

a. Absolute wind distribution errors

An accurate initial analysis is highly favorable for an accurate subsequent wind distribution forecast; in the < 24-hour forecast periods, the total wind distribution forecast error is comprised nearly equally from track forecast error and error in determining the extent of the winds; at 72-hr, the track forecast error contributes 6-8 times more to the total error than does the 72-hr wind analysis error;

and, thus, after 24 hours, the track error becomes the greatest contributor to the overall wind distribution error.

b. Average wind distribution forecast error (bias)

In general, the bias shows that in 1995, JTWC under-analyzed and under-forecast the strong sector wind distribution and over-analyzed and over-forecast the weak sector wind distribution, thus under-forecasting the asymmetry. In 1996, there was a tendency to under-analyze and under-forecast both sectors for 35-kt (17 m/sec) wind distribution. For the 50-kt (26 m/sec) wind distribution, the tendency was to under-forecast both sectors, even though the weak sector winds were over analyzed.

7.7 A PRELIMINARY STUDY OF GFDN-GENERATED WIND DISTRIBUTION FORECASTS

C. P. Guard
ONR-sponsored Research at University of
Guam
Mangilao, Guam 96923

The GFDN, the Navy adaptation of the GFDL high resolution hurricane model, provides a graphic display of the wind distribution predicted by the model. A preliminary study was conducted to assess the accuracy of the GFDN wind distribution predictions. The validation data base was taken from the study on JTWC wind distribution forecast capabilities. The absolute and average forecast errors were compared with those of the JTWC. The preliminary findings of the study are: (1) the model significantly under-forecast the strong sector winds and over-forecast the weak sector winds (to a lesser extent) for 35-kt (17 m/sec) winds, thus under-forecasting the asymmetry; (2) for 50-kt (26-kt m/sec) winds, both the strong and weak sectors were under forecast. The study also revealed that there

were some boundary problems with the output that have since been corrected.

7.8 PROGRESS ON A RESEARCH QUALITY, CONFIDENCE-BASED TC INTENSITY DATA BASE

C.P. Guard and M.A. Lander
ONR-sponsored Research at University of
Guam
Mangilao, Guam 96923

Work continued on the confidence-based TC intensity data base (IDB). This data base is needed because, in general, TC best-track (BT) IDBs are not of sufficient quality to be used as validation data for TC intensity research. There are several reasons for this shortfall, the most basic reason being that there is no way to discern the quality of the data on which a specific BT intensity is based. Different data platforms provide intensity data of varying accuracy, and from this knowledge, one can infer a certain level of confidence in that data.

a. Methodology of data base development

After determining the need for improving the JTWC IDB, a list of reasons for the needed changes was compiled. Examples of these are: landfall data not originally available, re-analysis of aircraft data, etc. Then, various data types were assessed for their accuracy in providing surface wind speeds, and each type was assigned a relative confidence value. Next, the JTWC "fix files" were reassessed and corrected where possible. Landfall data are being obtained from other countries, and these are being incorporated into the fix data base from which the IDB is developed. Translation speed, stability considerations, intensity spin up-spin down considerations, and appropriate wind-pressure relationships are also being used to make corrections.

b. Proposed Format and Availability

Once modifications are made, they will be put into a new data base, modified slightly from that of the preexisting JTWC BT data base. In addition to the data available in the JTWC format, the modified format includes the updated intensity value, the magnitude of the change, the coded reason for the change, and the relative accuracy or confidence of the intensity value. Initially, the data base will include data from the 1990s. Eventually, it will be expanded to the 1980s, 1970s, and earlier periods. The data base will reside on a web page in late 1997, and will be periodically updated as new data becomes available.

7.9 A WIND-PRESSURE RELATION-SHIP FOR MIDGET TCs IN THE WEST-ERN NORTH PACIFIC

C.P. Guard and M.A. Lander
ONR-sponsored Research at University of
Guam
Mangilao, Guam 96923

A new wind-pressure relationship (WPR) that relates maximum sustained surface winds in TCs to the minimum central pressure has been developed for western North Pacific (WNP) midget TCs. Midget TCs have a high intensity inner core where the outer winds are from the inertial spin down of the belt of maximum winds. There is no outer core. The WPR was based primarily on carefully selected data of midget TCs making landfall on islands and coastal areas of the WNP. Some aircraft data were used where the small TC size could be confirmed and where it was clear that the aircraft was in the strong sector of the TC. The new WPR indicates that these small TCs can have the same winds as larger TCs, but with a 10-17 mb higher central pressure, which corresponds to a 10-20-kt difference in wind speed. It also indicates that as the intensity approaches 130 kt (62 m/sec), the WPR converges with the WPR used for more normal sized TCs. This is because the midget TC usually acquires outer core characteristics.

The regression equation for the new WPR (for WNP midget TCs) is:

 $Vmax = 17.548(Pn-Pc)^{0.4345}$

Table 7-1 relates the maximum sustained wind with the minimum central pressure given by the new WPR (with Pn = 1010 mb) and that given by the Atkinson-Holliday WPR (Atkinson and Holliday 1977).

Table 7-1 A comparison of the maximum sustained winds (Vmax) with the minimum central pressure (Pc) in millibars for (a) midget TCs (new WPR) and (b) normal-sized TCs (Atkinson-Holliday WPR) (A & H).

	T		T		
	Pc	Pc		Pc	Pc
Vmax	midget	A&H	Vmax	midget	A&H
		<u>.l</u>			1, 1,
30		1000	105	949	939
35		997	110	943	934
40	1003	994	115	935	928
45	1002	991	120	928	922
50	1000	988	125	919	916
55	994	984	130	910	910
60	992	980	135	904	904
65	989	976	140	898	898
70	986	972	145	892	892
75	982	968	150	886	886
80	978	964	155	879	879
85	972	959	160	872	872
90	965	954	165	865	865
95	960	949	170	858	858
100	955	944			

7.10 A STUDY OF TC INTENSITY CHANGES USING THE DIGITAL DVORAK ALGORITHM

M. A. Lander
ONR-sponsored research at University of
Guam
Mangilao, Guam 96923

One of the utilities installed in the JTWC's MIDDAS satellite image processing equipment is an automated routine for computing Dvorak "T" numbers for tropical cyclones that possess eyes. The routine, developed by Zehr (personal communication), adapts the rules of the Dvorak technique as subjectively applied to enhanced infrared imagery (Dvorak 1984) in order to arrive at an objective T number, or "digital Dvorak" T number (hereafter referred to as DD numbers). Infrared imagery is available hourly from the GMS satellite, and hourly DD numbers were calculated for all of the typhoons of 1996 (and for some of the typhoons of 1995).

A preliminary study of the time series of the DD numbers shows that, in some cases, they differ substantially from the warning intensity and also from the subjectively determined T numbers obtained from application of Dvorak's technique. The output of the DD algorithm, when performed hourly, often undergoes rapid and large fluctuations. If the DD numbers truly represented rapid (on the order of 3 to 6 hours) intensity fluctuations with magnitudes (30-40 kt) as large as seen with some typhoons, there are two topics for further research: (1) how are the extremely rapid fluctuations of estimated intensity, if they are genuine, to be incorporated into the warning? And, (2) how can the best tracks, having had these rapid fluctuations removed, be used to study the processes governing what may prove to be real intensity fluctuations of the magnitude indicated by the DD numbers?

Another characteristic of the time series of the DD numbers emerges for most of the very intense typhoons: the DD numbers rise more quickly, and peak earlier, than do the subjectively determined T numbers. Also, within 24 hours of the peak, the DD numbers rapidly decrease to values as low as two T numbers below their peak value. A recovery is then observed before the DD numbers fall once again as the TC recurves and becomes extratropical. The cause of the rapid drop of the DD numbers after peaking is identifiable in nearly all cases of this phenomenon as the result of the formation of concentric eye wall clouds. A relatively precipitation-free moat forming between the concentric wall clouds causes the DD algorithm to yield a greatly reduced T number. When the outer wall cloud contracts and the inner wall cloud dissipates, the DD numbers rise. The behavior of the DD numbers may serve to highlight processes (such as eye wall replacement) and lead to a better understanding of them.

7.11 A LOOK AT GLOBAL TC ACTIVITY DURING 1995: CONTRASTING HIGH ATLANTIC ACTIVITY WITH LOW ACTIVITY IN OTHER BASINS

M.A. Lander and C.P. Guard
ONR-sponsored research at University of
Guam
Mangilao, Guam 96923

The 19 named TCs in the North Atlantic (NAT) during 1995 were nearly a record for that basin. During the past three decades, only the year 1969 — with its 18 TCs of at least tropical storm intensity — was nearly as prolific. During 1995 and 1969 (two years that have been designated herein as "prolific" years in the NAT), the annual number of TCs in most of the other TC basins was well-below normal (to such an extent that even the annual global number of TCs during these two years

was below normal). Despite the strong reduction of the annual number of TCs in most basins during the aforementioned NAT prolific years, there is no overall correlation between the annual number of TCs in the NAT and the annual number of TCs in any other major TC basin [i.e., the western North Pacific (WNP), eastern North Pacific (ENP), and Southern Hemisphere (SH)]. In fact, the only statistically significant correlations of annual numbers of TCs are weak positive correlations between the WNP and the ENP, between the SH and the WNP, and between the SH and the ENP. These weak positive correlations act to increase the variance of the annual global number of TCs.

There are only two large-scale atmospheric phenomena [i.e., ENSO and the Quasi-Biennial Oscillation (QBO)] that have been documented to have an effect on the annual number of TCs in the NAT and within the other TC basins. It has been shown that only within the NAT are the magnitude of these relationships strong. In all other major basins, the ENSO and the QBO have little, if any, effect on the annual number of TCs (although the formation regions of TCs within the WNP and the SH are shifted quite markedly by ENSO).

The global distribution of TCs during the NAT prolific years of 1969 and 1995 stands quite apart from the long-term relationships noted between the annual number of TCs in the NAT with the annual number of TCs in the other major TC basins. The ENSO and QBO can not alone account for the unusual distribution of TCs during 1969 and 1995. In fact, 1969 is considered by some to have been an El Niño year, while the global climatic anomalies during 1995 were considered by some to be representative of the cold phase of ENSO (i.e., La Niña). The only apparent commonality between 1969 and 1995 was that the QBO was in a westerly phase, a largescale atmospheric condition experienced approximately once every two years.

The NAT prolific year of 1995 need not herald the return to a higher number of NAT TCs such as has been documented to have occurred during the decades of the 1940s through 1960s. In fact, the NAT prolific year of 1969 was, in retrospect, a "herald" of lower NAT TC activity during the 1970s through the 1980s. It is hypothesized that NAT prolific years such as 1995 and 1969 will always be a characteristic of the NAT time series, regardless of inter-decadal changes in the average annual number of TCs in the NAT.

That the NAT prolific year of 1995 was a signal of global climate change is unlikely, considering that the phenomenon has occurred in the past, and that the global distribution of TCs during the previous NAT prolific year —1969 — was so strikingly similar. Based on the peculiar similarities between the global TC distribution of 1969 and 1995, it is hypothesized that the phenomenon of NAT prolific years (accompanying "meager" years in other basins) has its roots in a specific (but infrequent) state of the global atmosphere which does not appear to be related to ENSO, the QBO, inter-decadal changes in the annual number of TCs in the NAT, or long-term global climate change. Its mechanism remains a mystery.

7.12 UPDATING TC SATELLITE-DERIVED POSITION CODE NUMBER CRITERIA USED BY JTWC

T.R. Crume
Satellite Operations, Nimitz Hill, Guam
and
M.A.. Lander
ONR-sponsored research at University of
Guam
Mangilao, Guam 96923
and
R.T. Edson
Joint Typhoon Warning Center, Guam

In order to construct an accurate track history of a given TC from the many fixes obtained, it is desirable to have a methodology for determining not only the position, but also the reliability of that position. The Special Projects Section of Detachment 1, First Weather Wing (1WW) developed and published such a methodology in Pamphlet 105-10 (1WWP 105-10) entitled, Tropical Cyclone Position and Intensity Analysis Using Satellite Data (Arnold and Olsen 1974). One of the terms introduced in 1WWP 105-10 was Position Code Number (PCN). The PCN indicates the expected accuracy of the reported position. There are six PCNs: TCs with eyes (PCN 1 and 2); well defined circulation centers (CC) (PCN 3 and 4); and, poorly defined CC (PCN 5 and 6). Odd-numbered PCNs indicate geographical navigation of the gridding. Even-numbered PCNs indicate the gridding was based on satellite ephemerides alone.

Given the advances in technology, both in terms of image processing capabilities and the addition of new spectral windows, the process of assigning PCNs to TC fixes needs to be updated and improved. Specifically, the following recommendations are offered:

- (1) the guidance currently available for determining PCNs should be updated to reflect changes in advances in technology and the decrease in the relative numbers of PCNs 3 and 4,
- (2) a systematic categorization of fix types linked to specific PCNs (this includes concise documentation of the cloud features, sensor types, and specific image processing methodologies used to make the fix), should be made and
- (3) the relative accuracy of the fixes from the new image categories requires validation.

Satellite Operations is currently using a newly developed list of PCN categories. After a year, the error statistics of the PCN categories will be examined.

7.13 A TECHNIQUE FOR ESTIMATING THE INTENSITY OF TCs WHICH ARE UNDERGOING EXTRATROPICAL TRANSITION

D.W. Miller
Satellite Operations, Nimitz Hill, Guam
and
M.A. Lander
ONR-sponsored research at University of
Guam
Mangilao, Guam 96923

A review of western North Pacific synoptic data from 1994 through 1996 revealed that the intensity estimates of a significant number of typhoons that became extratropical were underestimated by the tropical satellite reconnaissance network using Dvorak's (1975, 1984) techniques. Occasional use of Hebert and Poteat's (H&P) (1975) technique for estimating the intensity of subtropical cyclones on these recurving typhoons also resulted in intensity estimates which were too low.

The application of Dvorak's techniques to TCs undergoing extratropical transition resulted in the intensity being underestimated by as much as three T numbers below the actual intensity as verified by synoptic data (good examples of this problem are described in Seth's summary in the 1994 ATCR; and in Dan's (06W) summary in this ATCR).

A technique to address the underestimation of the intensity of TCs which are undergoing extratropical transition (XT) was developed. The XT technique borrows from both Dvorak and H&P in the application of the log10 spiral to the primary outer cloud band, and, as in H&P, an incorporation of the effects of excess translational speed. Additional factors include: the degree of organization of the central and peripheral low- and mid-level clouds, and the extent of any resid-

ual or regenerative deep convection between the LLCC and the primary outer cloud band. These four factors are evaluated for wind speed contributions in the final determination of the "XT" number. The XT technique is an additive process whereby the TC intensity is derived from the addition of contributions from each of the applicable factors. There is a direct equivalence of Dvorak T numbers and XT numbers. The XT technique should be used until the satellite imagery indicates that the system has completed its transition into an extratropical cyclone. At that point it is recommended that a technique developed by Smigielski and Mogil (1992) for the estimation of the central SLP of extratropical cyclones be used if continued analysis is warranted. Further details of the XT technique are found in Miller and Lander (1997).

7.14 ON THE ABILITY OF OPERA-TIONAL DYNAMIC MODELS TO PRE-DICT TC INTENSITY

M.A.. Lander
ONR-sponsored research at University of
Guam
Mangilao, Guam 96923

For many years, operational dynamic models have been used to predict TC motion. In this area, the dynamic models generally out-perform baseline statistical measures of skill (e.g., CLIPER), and a steady improvement in their skill has been observed. More recently, increases in the spatial resolution, better physics, and (in some cases) improved bogussing techniques have rendered them capable of simulating TCs with realistic horizontal and vertical structure (e.g., a small region of very low pressure accompanied by high winds close to the low pressure center, and an outdraft cyclonic circulation in the upper troposphere). These dynamic models also have shown realistic genesis and develop-

ment of TCs such as the deepening of tropical depressions to typhoons within credible time spans. The intensity diagnoses and intensity forecasts of TCs in the western North Pacific (WNP) during 1996, made by several operational dynamic models (for which the analyzed and forecast intensity of TCs was routinely available at the JTWC, Guam), are evaluated with respect to the final best-track intensities produced by the JTWC. Dvorak (1975, 1984) observed that, on average, TCs intensify at a rate of one so-called "T" number per day. Each rise of a T number represents a 10-15-mb increase of intensity at the lower T numbers, to increases of approximately 30 mb per T number at the higher T numbers. Dvorak also categorized fast and slow development as an increase of 1.5 T numbers per day and 0.5 T numbers per day respectively. Additional categorizations of TC rates of intensification are rapid deepening (Holliday and Thompson 1979) and explosive deepening (Dunnavan 1983); these are 24-hr central pressure drops of at least 1.75 mb/hr for at least 12 hours and 2.75 mb /hr for at least 6 hours respectively. The results presented herein are based upon a preliminary examination of the dynamic model's (and JTWC's) ability to predict the 24-, 48- and 72-hour intensities of several of the WNP TCs of 1996. The only statistic evaluated was a simple comparison of the models' intensity trends with the intensity trends derived from the JTWC best tracks. Intensity trends were evaluated in a permutation of several forecast intervals: 0 to 24 hours, 0 to 48 hours, 24 to 48 hours, etc. A model's intensity prediction was scored as correct if its trend was in the same direction as the best track; even if the model changed by only 1 mb in the right direction and the best track changed by 70 mb. A model's intensity prediction was scored as incorrect if the trend was against the best track; no change in model intensity was scored as incorrect if the best track exhibited

any change. Examination of the intensity output of the various dynamic models also reveals some general characteristics. At the 0-to 24-hour forecast interval and the 0- to 48-hour forecast interval, most of the models have only modest skill over a random choice. At the extended forecast period of 48 to 72 hours, most of the models show no skill over a random choice. In fact, most of them are more often incorrect than correct. There are also large differences of skill from one TC to another.

Upon closer examination of the behavior of the model predictions of intensity, it is seen that the global spectral models have very small magnitudes of intensity change, while the regional models (e.g., GFDN), with their finer resolution and different physics packages, exhibit magnitudes of intensity change that are realistic. Also, the regional models have consistently higher skill over the global models at all permutations of forecast intervals. Further research is warranted to see if the models have any skill in flagging deviations of intensification from normal rates (e.g., rapid deepening, explosive deepening, and non-developing). A complete study of objective prediction of TC intensity must also include statistical intensity prediction schemes.

7.15 WATER VAPOR AND HIGH RESO-LUTION VISUALLY TRACKED WINDS FOR TC APPLICATIONS

T.L. Olander S.T. Wanzong C.S. Velden

Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin Madison, Wisconsin

and
J.D. Hawkins
Naval Research Laboratory
Monterey, CA 93943

and R.T. Edson Joint Typhoon Warning Center, Guam

Upper-level water vapor winds (Velden et al. 1997) and low-level cloud motion winds from high-resolution visible satellite imagery were derived and evaluated. These winds are derived from sequences of GMS-5 imagery accessed through the Bureau of Meteorology in Australia. Water vapor wind data sets were produced nominally at 12-hour intervals (00 and 12Z). However, during TC events, the frequency was increased to 6 hourly. The data sets were provided via Internet to JTWC for real time analysis. The data sets were also provided to FNMOC for inclusion into the operational NOGAPS model beginning in late July. Indications are the winds have made an immediate impact (improvement) on the NOGAPS upper-level analyses over the western North Pacific.

Special water vapor wind data sets were also produced over the Indian Ocean region during Naval exercises. These data sets were helpful in forecasting conditions for both the exercises, and TC monitoring in that region.

In 1996, UW-CIMSS began experimenting with a new product derived from sequences of high-resolution GMS visible imagery. Fields of high density, low-level cloud-tracked winds were derived and disseminated to JTWC for their evaluation. The fields were produced in the genesis region surrounding Guam at 00Z daily. However, during TC events the data set center was programmed to "float" with the center of the TC to provide coverage in the immediate TC environment. While several minor problems were discovered with the product, the winds show promise with further R&D to provide information on both TC genesis and size.

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APPENDIX A DEFINITIONS

BEST TRACK - A subjectively smoothed path, versus a precise and very erratic fix-to-fix path, used to represent tropical cyclone movement, and based on an assessment of all available data.

BINARY INTERACTION - A mutual cyclonic orbit of two tropical cyclones around their centroid. Lander and Holland (1993) showed that the behavior of most binary tropical cyclones consists of an approach, sudden capture, then a period of steady cyclonic orbit followed by a sudden escape or (less frequently) a merger (see Figure A-1).

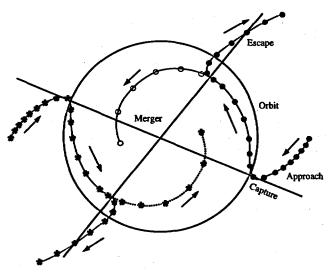


Figure A-1 Model of binary interation of two tropical cyclones that contain the major elements of approach and capture, followed by mutual orbit, then escape, or merger.

CENTER - The vertical axis or core of a tropical cyclone. Usually determined by cloud vorticity patterns, wind and/or pressure distribution.

EPHEMERIS - Position of a body (satellite) in space as a function of time; used for gridding satellite imagery. Since ephemeris gridding is

based solely on the predicted position of the satellite, it is susceptible to errors from vehicle wobble, orbital eccentricity, the oblateness of the Earth, and variation in vehicle speed.

EXPLOSIVE DEEPENING - A decrease in the minimum sea-level pressure of a tropical cyclone of 2.5 mb/hr for at least 12 hours or 5 mb/hr for at least six hours (Dunnavan 1981).

EXTRATROPICAL - A term used to indicate that a cyclone has lost its "tropical" characteristics. The term implies both poleward displacement from the tropics and the conversion of the cyclone's primary energy source from the release of latent heat of condensation to baroclinic processes. In the XT technique (Miller and Lander 1997a) a tropical cyclone is defined as having completed extratropical transition when the circulation center has moved poleward of the polar jet maximum or when water vapor imagery clearly indicates the system has become entirely cold-core. It is important to note that cyclones can become extratropical and still maintain winds of typhoon or storm force.

EYE - The central area of a tropical cyclone when it is more than half surrounded by wall cloud.

INTENSITY - The maximum sustained 1-minute mean surface wind speed, typically within one degree of the center of a tropical cyclone.

MAXIMUM SUSTAINED WIND - The highest surface wind speed averaged over a 1-minute period of time. (Peak gusts over water average 20 to 25 percent higher than sustained winds).

MEI-YU FRONT - The Term "mei-yu" is the Chinese expression for "plum rains". The mei-yu front is a persistant east-west zone of disturbed weather during spring which is quasi-stationary and stretches from the east China coast, across Taiwan, and eastward into the Pacific south of Japan.

MONSOON DEPRESSION - A tropical cyclonic vortex characterized by: 1) its large size, the outer-most closed isobar may have a diameter on the order of 600 nm (1000 km); 2) a loosely organized cluster of deep convective elements; 3) a low-level wind distribution which features a 100-nm (200-km) diameter light-wind core which may be partially surrounded by a band of gales; and, 4) a lack of a distinct cloud system center. Note: most monsoon depressions which form in the western North Pacific eventually acquire persistent central convection and accelerated core winds marking its transition into a conventional tropical cyclone.

MONSOON GYRE - A mode of the summer monsoon circulation of the western North Pacific characterized by: 1) a very large nearly circular low-level cyclonic vortex that has an outer-most closed isobar with diameter on the order of 1350 nm (2500 km); 2) a cloud band rimming the southern through eastern periphery of the vortex/surface low; 3) a relatively long (two week) life span - initially, a subsident regime exists in its core and western and northwestern quadrants with light winds and scattered low cumulus clouds; later, the area within the outer closed isobar may fill with deep convective cloud and become a monsoon depression or tropical cyclone; and, 4) the large vortex cannot be the result of the expanding wind field of a preexisting monsoon depression or tropical cyclone. Note: a series of small or very small tropical cyclones may emerge from the "head" or leading edge of the peripheral cloud band of a monsoon gyre (JTWC 1993; Lander 1994a).

RAPID DEEPENING - A decrease in the minimum sea-level pressure of a tropical cyclone of 1.75 mb/hr or 42 mb for 24-hours (Holliday and Thompson 1979).

RECURVATURE - The turning of a tropical cyclone from an initial path toward the west and poleward to east and poleward, after moving poleward of the mid-tropospheric subtropical ridge axis.

REVERSE-ORIENTED MONSOON TROUGH - The distinguishing characteristics of a reverse-oriented monsoon trough in the western North Pacific are a SW-NE (i.e., reverse) orientation of the trough axis with respect to the normal NW-SE orientation of the trough axis, and the penetration of the trough axis into subtropical areas normally the province of easterly flow.

SIGNIFICANT TROPICAL CYCLONE - A tropical cyclone becomes "significant" with the issuance of the first numbered warning by the responsible warning agency.

SIZE - The areal extent of a tropical cyclone, usually measured radially outward from the center to the outer-most closed isobar. Based on an average radius of the outer-most closed isobar, size categories in degrees of latitude follow: $< 2^{\circ} = \text{very small}$, 2° to $3^{\circ} = \text{small}$, 3° to $6^{\circ} = \text{medium}$ (average), 6° to $8^{\circ} = \text{large}$, and 8° or greater = very large (Brand 1972 and a modification of Merrill 1982).

STRENGTH - The average wind speed of the surrounding low-level wind flow, usually measured within a one to three degree annulus of the center of a tropical cyclone (Weatherford and Gray 1985).

SUBTROPICAL CYCLONE - A low pressure system that forms over the ocean in the subtropics and has some characteristics of a tropical circulation, but not a central dense overcast. Although of upper cold low or low-level baroclinic origins, the system can transition to a tropical cyclone.

SUPER TYPHOON - A typhoon with maximum sustained 1-minute mean surface winds of 130 kt (67 m/sec) or greater.

TROPICAL CYCLONE - A non-frontal, migratory low-pressure system, usually of synoptic scale, originating over tropical or subtropical waters and having a definite organized circulation.

TROPICAL DEPRESSION - A tropical cyclone with maximum sustained 1-minute mean surface winds of 33 kt (17 m/sec) or less.

TROPICAL DISTURBANCE - A discrete system of apparently organized convection, generally 100 to 300 nm (185 to 555 km) in diameter, originating in the tropics or subtropics, having a non-frontal, migratory character and having maintained its identity for 12- to 24-hours. The system may or may not be associated with a detectable perturbation of the low-level wind or pressure field. It is the basic generic designation which, in successive stages of development, may be classified as a tropical depression, tropical storm, typhoon or super typhoon.

TROPICAL STORM - A tropical cyclone with maximum 1-minute mean sustained surface winds in the range of 34 to 63 kt (18 to 32 m/sec), inclusive.

TROPICAL UPPER-TROPOSPHERIC TROUGH (TUTT) - A dominant climatological system and a daily upper-level synoptic feature of the summer season, over the tropical North Atlantic, North Pacific and South Pacific Oceans (Sadler 1979). Cold core lows in the TUTT are referred to as cells, or TUTT cells.

TYPHOON (HURRICANE) - A tropical cyclone with maximum sustained 1-minute mean surface winds of 64 to 129 kt (33 to 66 m/sec). West of 180° E longitude they are called typhoons and east of 180° E longitude hurricanes.

WALL CLOUD - An organized band of deep cumuliform clouds that immediately surrounds the central area of a tropical cyclone. The wall cloud may entirely enclose or partially surround the center.

WESTERLY WIND BURST - A short-duration low-level westerly wind event along and near the equator in the western Pacific Ocean (and sometimes in the Indian Ocean) (Luther et al. 1983). Typically, a westerly wind burst (WWB) lasts several days and has westerly winds of at least 10 kt (5 m/sec) (Keen 1988). Most WWBs occur during the monsoon transition months of April-May, and November-December. They show some relationship to the ENSO phenomenon (Luther et al. 1983; Ramage 1986). Some WWBs are even more energetic, with wind speeds of 30 kt (15 m/sec) observed during well-developed systems. These intense WWBs are associated with a large cluster of deep-convective cloud along the equator. An intense WWB is a necessary precursor to the formation of tropical cyclone twins symmetrical with respect to the equator (Keen 1982; Lander 1990).

APPENDIX B NAMES FOR TROPICAL CYCLONES IN THE WESTERN NORTH PACIFIC OCEAN AND SOUTH CHINA SEA

Column 1		Column 2		Column 3		Column 4	:
ANN	AN	ABEL	A-bel	AMBER	AM-ber	ALEX	AL-x
BART	BART	BETH	BETH /	BING	BING	BABS	BABS
CAM	KAM	CARLO	KAR-lo	CASS	KASS	CHIP	CHIP
DAN	DAN	DALE	DAY-U	DAVID	DAY-vid	DAWN	DAWN
EVE	EEV	ERNIE	ER-nee	ELLA	EL-la	ELVIS	EL-vis
FRANKIE	FRANK-ee	FERN	FERN	FRITZ	FRITZ	FAITH	<i>FAITH</i>
GLORIA	GLOR-ee-uh	GREG	GREG	GINGER	JIN-jer	GIL	GIL
HERB	HERB	HANNAH	HAN-nah	HANK	HANGK	HILDA	HIL-dah
IAN	EE-an	ISA	EE-sah	IVAN	I-van	IRIS	I-ris
JOY	JOY	JIMMY	JIM-ee	JOAN	JONE	JACOB	JAY-kob
KIRK	KIRK	KEĽLY	KEL-lee	KEITH	KEETH	KATE	KATE
LISA	LEE-sah	LEVI	LEEV-eye	LINDA	LIN-dah	LEO	LEE-o
MARTY	MAR-tee	MARIE	mah-REE	MORT	MORT	MAGGIE	MAG-gee
NIKI	NI-kee	NESTOR	NES-tor	NICHOLE	nik-KOL	NEIL	NEEL
ORSON	OR-son	OPAL	O-pel	OTTO	OT-tow	OLGA	OL-gah
PIPER	PI-per	PETER	PEE-ter	PENNY	PEN-nee	PAUL	PAUL
RICK	RICK	ROSIE	RO-zee	REX	REX	RACHEL	RAY-chel
SALLY	SAL-lee	SCOTT	SKOT	STELLA	STEL-lah	SAM	SAM
TOM	TOM	TINA	TEE-nah	TODD	TOD	TANYA	TAHN-yah
VIOLET	VI-uh-let	VICTOR	vik-TOR	VICKI	VIK-kee	VIRGIL	VER-jil
WILLIE	WIL-lee	WINNIE	WIN-nee	WALDO	WAL- do	WENDY	WEN-dee
YATES	YATES	YULE	YOU-I	YANNI	YAN-ni	YORK	YORK
ZANE	ZANE	ZITA	ZEE-tah	ZEB	ZEB	ZIA	ZEE-uh

NOTE 1: Assign names in rotation, alphabetically, starting with (ANN) for first tropical cyclone of 1996. When the last name in Column 4 (ZIA) has been used, the sequence will begin again with the first name in Column 1 (ANN).

NOTE 2: Pronunciation guide for names is italicized.

SOURCE: CINCPACINST 3140.1W

APPENDIX C CONTRACTIONS

AB	Air Base	MRQ	Automated Response to Query	COMNAVI	METOCCOM or CNMOC Commander
ABW	Air Base Wing	ATCF'	Automated Tropical		Naval Meteorology and Oceanography Command
ABIO	Significant Tropical Weather Advisory for the Indian Ocean	ATCR	Cyclone Forecast (system) Annual Tropical	СРА	Closest Point of Approach
ABPW	Significant Tropical Weather Advisory for the Western Pacific Ocean	AUTODIN	Cyclone Report Automated Digital Network	CPHC CSC	Central Pacific Hurricane Center Cloud System Center
ACCS	Air Control Center Squadron	AVHRR	AdvancedVery High Resolution Radiometer	CSUM	Colorado State University Model
ACFT	Aircraft	AWDS	Automated Weather Distribution System	CW	Continuous Wave
ADEOS	Japanese Advanced Earth Observing	AWN	Automated Weather Network	DAVE	Dynamic Average
	Satellite	BLND	Blended (Hybrid Aid)	DD	Digital Dvorak
ADP	Automated Data Processing	BRAC	Base Realignment and Closure	DDN DEG	Defense Data Network Degree(s)
AFB	Air Force Base	CDO	Central Dense Overcast	DFS	Digital Facsimile
AFDIS	Air Force Dial-In System	CI	Current Intensity	DISN	System Defense Information
AFGWC	Air Force Global Weather Central	CIMSS	Cooperative Institute for Meterological Satellite		Systems Network
AIREP	Aircraft (Weather) Report	CIV	Studies Civilian	DMS	Defense Messaging System
AJTWC	Alternate Joint Typhoon Warning Center	CLD	Cloud	DMSP	Defense Meteorological Satellite Program
AMOS	Automated	CLIM	Climatology	DOD	Department of Defense
	Meteorological Observing Station	CLIP or CLIPER	Climatology and Persistence Technique	DSN	Defense Switched Network
AOR	Area of Responsibility	CM	Centimeter(s)	DTG	Date Time Group
ARC	Automated Remote Collection (system)	C-MAN	Coastal-Marine Automated Network	EGRR	Bracknell Model
ARGOS	(International Service for Drifting Buoys)	CMOD	Compact Meteorological and Oceanographic Drifter (buoy)	ENSO	El Niño-Southern Oscillation

ERS	European Remote	ICAO	International Civil	MET	Meteorological
	Sensing Satellite		Aviation Organization	,	<i>(</i>
		INIT	Initial	METEOSAT	C European
FBAM	FNMOC Beta and				Meteorological Satellite
	Advection Model	INST	Instruction		Wicker Diogram Salonice
•	114 40011011 1/10401	11101	instruction .	MIDDAS	Meteorological
FI	Forecast Intensity	IP	Internet Protocol	MIDDAS	
A. B	(Dvorak)	II.	internet Protocor		Imagery, Data Display,
, •	(Dvorak)	tro	To Come and	*.	and Analysis System
ET DATERANA	PEOCOEN	I R	Infrared	2.5727	
FLENUMM				MIN	Minimum
or FNMOC	_ · · · · · · · · · · · · · · · · · · ·	JGSM	Japanese Global		
	Meteorology and		Spectral model	MINI-MET	Mini-Meteorological
	Oceanography Center				(buoy)
		JTWC 💉	Joint Typhoon Warning		
FT	Foot/Feet	/	Center	MISTIC	Mission Sensor Tactical
		\mathcal{L}_{i}	<i>:</i>		Imaging Computer
FTP	File Transfer Protocol	JTWC92	Statistical-Dynamical		
		or JT92	Objective Technique	MM	Millimeter(s)
GCA	Great Circle Arc		,		()
		JTYM	Japanese Typhoon	MOVG	Moving
GFDN	Geophysical Fluid		Model	111010	Moving
GI Di	Dynamics - Navy		1710401	MSLP	Minimum Sea-level
	Dynamics - Navy	KM	Kilometer(s)	WISLF	
GMS	Ianan Gaastatianan	WIAI	Anometer(s)		Pressure
GMS	Japan Geostationary	` 12T	Vm e4/e)		341
	Meteorological Satellite	KT	Knot(s)	MSU	Microwave Sounding
~~~		T 4 5 7			Unit
GMT	Greenwich Mean Time	LAN	Local Area Network		
	1			NARDAC	Naval Regional Data
GOES	Geostationary .	LAT	Latitude		Automation Center
	Operational J				
	Environmental Satellite	LLCC	Low-Level Circulation	NAS	Naval Air Station
	, ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) (		Center		
GSRS	Geostationary Satellite			NASA	National Aeronautics
	Receiving System	LONG	Longitude		and Space
					Administration
GTS	Global Telecommun-	LUT	Local User Terminal		
	ications System			NAVPACME	TOCCEN or NPMOC
		LVL	Level		Naval Pacific
HIRS	High Resolution		4 17 2		Meteorology and
	Infrared Sounder	M	Meter(s)		Oceanography Center
	Innuica Sounds		wiciel(s)	: -	
hPa	Hectopascal	MAX	Maximum		(Hawaii)
ша	ricciopascai	MAA	Maximum	BIASIDA CREE	TO COPIL WEST
HPAC	Mean of XTRP and	MB	Mallanda		TOCCEN WEST
пгас		MID	Millibar(s)	or NPMOCW	
	CLIM Techniques (Half Persistence and	36D 436	34. U. D.		Naval Pacific
		MBAM	Medium Beta and		Meteorology and
	Climatology)		Advection Model		Oceanography Center
					West (Guam)
HF	High Frequency	MCAS	Marine Corps	NORR	
			Air Station		National Centers for
·HR	Hour(s)				Environmental
		MCS	Mesoscale Convective		Prediction
HRPT	High Resolution		System		
	Picture Transmission		-	NEDN	Naval Environmental
		4.5	₽ <u>-</u>		Data Network
	1				

	£				,
NESDIS	National Environmental Satellite, Data, and	NRL-MRY	Naval Research Laboratory at Monterey,	PIREP	Pilot Weather Report(s)
•	Information Service	<u>.</u>	CA	QBO	Quasi-Biennial Oscillation
NESN	Naval Environmental Satellite Network	NSCAT	NASA Scatterometer	RADOB	Radar Observation
• •		NSDS-G	Naval Satellite Display	RECON	Reconnaissance
NEXRAD	Next Generation (Doppler Weather)	. 3	System - Geostationary	RECR	Recurve (Forecast Aid)
	Radar (WSR-88D)	NTWP	Naval Telecommunications	RMSE	Root mean square error
NGDC	National Geophysical Data Center		Area Master Station, Western Pacific	ROCI	Radius of outer-most closed isobar
NHC	National Hurricane Center	SIPRNET	Secret Internet Protocol Router Network	SAT	Satellite
NIPRNET	Non-secure Internet	NWP	Northwest Pacific	SCS	South China Sea
	Protocol Router Network	NWS	National Weather Service	SDHS	Satellite Data Handling System
NM	Nautical Mile(s)	OBS	Observations	SEC	Second(s)
NMC	National Meteorological Center (now NCEP)	OLS	Operational Linescan System	SFC	Surface
NOAA	National Oceanic and			SGDB	Satellite Global Data
NOAA	Atmospheric	ONR	Office of Naval	Ì	Base
•	Administration		Research	SIPRNET	Secret Internet Protocol
NODDES	Naval Oceanographic	oss	Operations Support Squadron		Router Network
e e e	Data Distribution and		Squauron	SLP	Sea-Level Pressure
	Expansion System	OSB	Ocean Sciences Branch	SPAWARS	YSCOM Space and
NODDS	Naval Oceanography Data Distribution System	OTCM	One-Way (Interactive) Tropical Cyclone Model		Naval Warfare Systems Command
NOGAPS	Navy Operational	PACAF	Pacific Air Force	SPIDR	Space Physics Interactive Data
or NGPS	Global Atmospheric Prediction System	PACMEDS	Pacific Meteorological Data System		Resource
NORAPS	Navy Operational	PACOM	Pacific Command	SSM/I	Special Sensor Microwave/Imager
or NRPS	Regional Atmospheric			SST	Sea Surface
	Prediction System	PAGASA	Philippine Atmospheric, Geophysical, and		Temperature
NPS	Naval Postgraduate School		Astronomical Services Administation	SSU	Stratosphere Sounding Unit
NR	Number	PC	Personal Computer	ST	Subtropical
NRL	Naval Research Laboratory	PCN	Position Code Number	STNRY	Stationary
		PDN	Public Data Network		

STR	Subtropical Ridge	TOGA	Tropical Ocean Global Atmosphere	WESTPAC or WNP	Western (North) Pacific
STRT	Straight (Forecast Aid)	TOVS	TIROS Operational	WGTD	Weighted (Hybrid Aid)
STY	Super Typhoon	i.	Vertical Sounder		
SWDIS	Satellite Weather Data Imaging System	TS	Tropical Storm	WMO	World Meteorological Organization
TAPT	Typhoon Acceleration	TUTT	Tropical Upper- Tropospheric Trough	WRN or WRNG	Warning(s)
TPC	Prediction Technique	TY	Typhoon	WSD	Wind Speed and
TC	Tropical Cyclone	TYAN	Typhoon Analog		Direction
TCFA	Tropical Cyclone Formation Alert		(Forecast Aid)	WSR-88D	Weather Surveillance Radar - 1988 Doppler
TD	Tropical Depression	ULCC	Upper-Level Circulation Center	WVTW	Water Vapor Tracked
TDA	Typhoon Duty Assistant	US	United States		Winds
TDO	Typhoon Duty Officer	USAF	United States Air Force	WWB	Westerly Wind Burst
TELEFAX	Telephone Facsimile	USCINCPAC	C Commander-in-Chief Pacific (AF - Air	www	World Wide Web
TESS	Tactical Environmental		Force, FLT - Fleet)	XT	Extratropical
	Support System	USN	United States Navy	XTRP	Extrapolation
TIFF	Tagged Image File Format	VIS	Visual	z	Zulu time
TIROS-N	Television Infrared Observational Satellite- Next Generation	WAN	Wide Area Network		(Greenwich Mean Time/Universal Coordinated Time)

11.

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Copies of the past Annual Tropical Cyclone Reports for DOD agencies or contractors can be obtained through:

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TROPICAL CYCLONE RECONNAISSANCE
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OBJECTIVE FORECASTING TECHNIQUES
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